

2 Remedial Investigation Summary

This section summarizes information from the Remedial Investigation (RI) Report for the Lower Fox River and Green Bay that is relevant to the feasibility study. Specifically, this summary of the RI Report will:

- Define the historical setting, including sources of chemicals of concern in the Lower Fox River;
- Describe the physical characteristics of the Lower Fox River and Green Bay along areas of impacted sediment deposits;
- Estimate the occurrence, volume, and mass of sediments containing identified chemical compounds, particularly polychlorinated biphenyls (PCBs);
- Discuss the fate and transport of contaminants within the Lower Fox River and Green Bay; and
- Present the results of an analysis of time trends within the Lower Fox River for changing sediment and fish tissue concentrations.

References and data sources pertaining to information presented in the RI summary can be found in the *Lower Fox River and Green Bay Remedial Investigation Report* (RETEC, 2002a).

2.1 Environmental Setting and Background

2.1.1 Lower Fox River Setting

The Lower Fox River flows northeast approximately 63 kilometers (km) (39 miles) from Lake Winnebago to Green Bay, Wisconsin (Figure 1-1). The Lower Fox River is the primary tributary to lower Green Bay, draining approximately 16,395 square kilometers (km²) (6,330 square miles [mi²]) with a mean discharge of 122 cubic meters (m³) per second (4,300 cubic feet per second [cfs]). The change in river elevation between Lake Winnebago and Green Bay is approximately 51 meters (168 feet).

Reach Designations

To facilitate modeling activities and identification of specific points along the river, the Lower Fox River was divided into the following four separate reaches in sequential order going downstream:

- Little Lake Butte des Morts (LLBdM),
- Appleton to Little Rapids,
- Little Rapids to De Pere, and
- De Pere to Green Bay (also Green Bay Zone 1).

These four reaches were based on similar water depths, current velocities, contaminant concentrations and distribution, and dam/lock structures (Figures 2-1 through 2-4). These reach designations were used during the RI to streamline the evaluation and reporting of sediment, water, and biological tissue data. Specific sediment deposits were identified in the first three reaches (Little Lake Butte des Morts, Appleton to Little Rapids, and Little Rapids to De Pere). These deposits were labeled A through HH and POG. Deposits were originally designated based on physical attributes, then later the chemical nature and extent of each deposit was determined. The De Pere to Green Bay Reach was divided into 96 Sediment Management Units (SMUs) to support the modeling efforts of the 1989 Green Bay Mass Balance Study. Table 2-1 summarizes the 35 sediment deposits (labeled A through HH) upstream of the De Pere dam and 96 Sediment Management Units (SMUs 20 through 115) downstream of the De Pere dam.

2.1.2 Green Bay

Green Bay is a narrow, elongated bay, approximately 190 km (119 miles) in length and an average of 37 km (23 miles) in width (Figure 1-2). The bay is bounded by the city of Green Bay at the south end and by both Big and Little Bays de Noc, in Michigan's Upper Peninsula (UP), on the north end. Wisconsin's Door Peninsula separates the majority of Green Bay from Lake Michigan. Urban areas located along the west shore of Green Bay include the cities of Marinette, Peshtigo, and Oconto, Wisconsin, and Escanaba and Menominee, Michigan. The city of Sturgeon Bay, Wisconsin, is located on the east shore of Green Bay.

The Green Bay watershed drains approximately 40,000 km² (15,625 mi²) or about one-third of the Lake Michigan drainage basin. Two-thirds of the Green Bay drainage is in Wisconsin and one-third is in Michigan. The Lower Fox River is the largest tributary to Green Bay, contributing approximately 42 percent of the total drainage, over 95 percent of the PCB load, and 70 percent of the suspended sediments. Other significant tributaries located along the west and north sides of the bay include Duck Creek and the following rivers: Suamico, Pensaukee, Oconto, Peshtigo, Menominee, Cedar, Ford, Escanaba, Tacoosh, Rapid, Whitefish, Sturgeon, and Fishdam.

Zone Designations

The Green Bay Mass Balance Study (GBMBS) (EPA, 1989a) divided the bay into four morphometric zones based on physical/chemical/biological characteristics

observed in the bay: identified as zones 1, 2, 3, and 4 (Figure 1-2). Observations included eutrophication, chemical contaminants, foraging areas, habitat gradients, and distribution of fish populations. Green Bay Zone 1 is the same as the De Pere to Green Bay Reach of the Lower Fox River. Zones 2 and 3 are further divided into A and B segments by a center line extending out from the mouth of the Lower Fox River to Chambers Island. Zones 2A and 3A are located on the west side of this line while zones 2B and 3B are located on the east side of this line. Table 2-2 summarizes the physical characteristics of the Green Bay zones.

2.1.3 Site History

The Lower Fox River and Green Bay regions have long been important transportation corridors within the state of Wisconsin. Abundant and reliable food, as well as other natural resources in the area, have fostered development since prior to the arrival of Europeans to the region. By the early 1800s, timber, agriculture, fishing and fur trading, and other commercial activities were either well established or beginning to be developed, due to the availability of local resources. During the 1820s and 1830s, Green Bay was a key entrance into the American west and large-scale migration to the area and development occurred (Burridge, 1997). In 1839–40, representatives of the U.S. federal government (the Topographical Engineers office) recommended the construction of a series of dams, locks, canals, and other improvements in order to make the Lower Fox River navigable between Green Bay and Lake Winnebago. Channelization of the Lower Fox River began as part of this effort, as did construction of the locks and dams at each of the river's rapids. Along with development came utilization, exploitation, and degradation of the local resources, including the water quality of the river and bay.

2.1.4 Current Land Use

Currently, the Green Bay and Lower Fox River areas support a population of approximately 595,000, about 10 percent of the state's population. The Lower Fox River valley, especially in the Appleton and Neenah-Menasha area, may still contain the largest concentration of pulp and paper industries in the world (20 mills in approximately 37 miles). The paper industry remains active within the valley and plays a vital role in the local and state economy. Other industries important to the region include metal working, printing, food and beverages, textiles, leather goods, wood products, and chemicals. In addition to heavy industrial land use, the region also supports a mixture of agricultural, residential, light industrial, conservation, and wetland areas.

Regional land use along the Lower Fox River is identified on maps prepared by planning commissions in both the Fox Cities and Brown County. Land use details on these maps provide a general description of development in the river vicinity.

The approximated general land use percentages for areas within about 0.25 mile of the bank of the Lower Fox River are summarized below.

Land Use ¹	Fox River Cities ² (1996)	Brown County (1990)	Entire River
Residential	32.9%	25.5%	29.2%
Industrial/Commercial	26.2%	25.3%	25.8%
Woodlands	14.6%	17.9%	16.2%
Parks	11.6%	6.8%	9.3%
Agricultural	0.5%	11.4%	5.8%
Public ³	7.2%	1.3%	4.3%
Wetlands	5.1%	1.6%	3.4%
Vacant	1.9%	10.2%	6.0%

Notes:

- ¹ Percentages are approximate and are intended to provide a general indication of land use along the Lower Fox River.
- ² The Fox Cities includes all communities between Neenah/Menasha and Kaukauna.
- ³ Public land includes school properties.

The majority of the Lower Fox River is accessible to the public, including individual landowners along the banks. About 25 percent of the river shoreline area is considered wildlife habitat (agriculture, woodland, wetland). The wildlife habitat is largely located between Kaukauna and De Pere in both the Appleton to Little Rapids and Little Rapids to De Pere reaches.

Land use in the vicinity of Green Bay was collected from available county records for Brown, Door, Kewaunee, Oconto, and Marinette counties in Wisconsin and for Delta and Menominee counties in Michigan. A summary of the land use in the counties bordering Green Bay is presented in Table 2-3. The counties located along Green Bay are largely undeveloped. Brown County, Wisconsin is the only county where more than 5 percent of the total land is used for residential or industrial/commercial purposes. Also, between 65 and 85 percent of all land in these counties is classified as either agricultural or forested, reflecting the overall rural nature of this area. Wetlands comprise 3 to 20 percent of the land in the counties. The largest wetland areas are located in Brown, Oconto, and Marinette counties, all located along the western side of Green Bay. Door County, located on the eastern side of the bay, has less than 3.3 percent wetlands.

2.2 Physical Characteristics

Knowledge of the physical characteristics of a site provide the foundation for developing a site conceptual model and understanding the distribution and

transport of contaminants throughout the river/bay system. Physical characteristics briefly described in this section for the Lower Fox River and Green Bay include: regional geology, sediment grain size, river and bay bathymetry, surface water hydrology, and sediment bulk density. In addition, a brief history of dredging activities is provided. The RI Report contains considerably more detail for each of these subjects.

2.2.1 Geologic Characteristics

Presented here is a brief summary of geology in the Lower Fox River and Green Bay basins. The RI contains considerably more detail pertaining to the bedrock formations, glacial stratigraphy, and native material underlying the recent soft sediment deposits.

Regional Geologic Setting

The Lower Fox River and Green Bay basins lie in the ridges and lowlands province of eastern Wisconsin and western Michigan. The eastern ridges and lowlands generally trend north-south across Wisconsin from northeastern Illinois to the Michigan shores of Lake Superior. The bedrock does not entirely control surface geomorphology, as the glacial advances and retreats planed off the bedrock highs and filled in bedrock valleys with till and outwash deposits.

The Lower Fox River valley and Green Bay is underlain by a bedrock sequence of Precambrian granite overlain by Paleozoic sandstones, dolomite, and shale. The surface of the bedrock units slope east, approximately 5.7 to 7.6 meters per kilometer (m/km) (30 to 40 feet per mile), toward and beneath Lake Michigan. This regional dip has resulted in the Silurian Niagara Escarpment, east of and parallel to the Lower Fox River lowlands, and erosion of the Ordovician Maquoketa shale in the western part of the study area.

Due to the erosion of the Silurian dolomite and Ordovician shale bedrock units, the uppermost bedrock in the Lower Fox River valley and along the western side of Green Bay (from the city of Green Bay to Little Bay de Noc) are Ordovician age limestone/dolomite units. Additionally, bedrock units of the western shore of Green Bay are comprised of the Galena and Platteville formations. Within Michigan, these units are referred to as the Trenton and Black River Formation and they are contemporaneous with the Galena and Platteville units.

Glacial Geology and Regional Soils

Unconsolidated Quaternary glacial deposits cover the bedrock units and consist of silty clay to clay loam tills with associated sand and gravel outwash and lacustrine units. In the Lower Fox River valley, the glacial deposits range in thickness from approximately 15 meters (50 feet) over much of the area to over

61 meters (200 feet) in the area around Wrightstown (Attig *et al.*, 1988). On the Door and Garden peninsulas, these deposits are generally less than 3 meters (10 feet) thick, and are thinner along the shores of the bay.

Soils and river sediments in the region are predominantly silt and clay units with varying amounts of sand and gravel due to the glacial events that occurred in region. The glacial deposits also affect the surficial soils in the vicinity of the Lower Fox River, many of which are described as silty clay loam, silty clay, and clay. In the northern portion of Green Bay, especially along the west side of the bay, outwash and glacial lake plains (typically dominated by sands) developed and ultimately affected soil formation, while on the Door and Garden peninsulas, clay till deposits are predominant. Superimposed on the glacial deposits are modern fluvial and alluvial sediments associated with slopewash, river, and floodplain deposits (Krohelski and Brown, 1986).

2.2.2 Sediment Grain Size

The Lower Fox River sediment grain size distribution reflects the mixture of sand, silt, and clay comprising the native silty clay glacial till deposits of the area. Sand and silt are the dominant grain sizes in Lower Fox River sediments, typically accounting for 75 to 90 percent of the particle sizes present.

In Little Lake Butte des Morts, the Appleton to Little Rapids Reach, and the De Pere to Green Bay Reach, silt comprises about 40 percent of the sediments encountered, while the sand content ranges between 41 and 46 percent. However, in the Little Rapids to De Pere Reach, where extensive sediment accumulations have been observed at Deposit EE, the silt content is 54 percent while sand comprises only about 23 percent of the sediments. These results confirm that the De Pere dam is a significant trap for finer-grained sediments on the Lower Fox River.

Sediments within Green Bay have a higher percentage of sand than those in the river. Sand content in Zone 2 (2A/2B) ranges between about 52 and 93 percent, with an average of 73 percent. In Zone 3A, along the west side of Green Bay, sand content is greater than 97 percent, while the sand content in Zone 3B generally ranges between 60 and 80 percent. The results for Zone 3B reflect the influx of sediments from the Lower Fox River, with a slightly higher silt/clay content in this area than in the other three areas of Green Bay. In Zone 4, the sand content averages 96 percent, which is similar to Zone 3A. Overall, the average sand content of the bay is 78 percent.

Atterberg Limits data collected during the 1993 and 1998 sampling activities characterized the sediments by high liquid and plastic limits. Under the Unified

Soil Classification System (USCS), the majority of the sediments were classified as high-compressibility silts (MH) while a small percentage were classified as highly plastic clays (CH).

2.2.3 Lower Fox River Bathymetry

The Lower Fox River is relatively narrow, generally less than 305 meters (1,000 feet) wide over much of its length, and ranges up to approximately 6.1 meters (20 feet) deep in some areas. Where the river widens significantly, water depths generally decrease to less than 3 meters (10 feet) and in the case of Little Lake Butte des Morts, water depths range between 0.61 and 1.53 meters (2 and 5 feet) except in the main channel. In general, however, the main channel of the river ranges from approximately 1.8 to 6.1 meters (6 to 20 feet) deep. Bathymetry information from the NOAA recreational charts (NOAA, 1992) is included on Figures 2-5 through 2-8.

The Little Lake Butte des Morts Reach is approximately 10 km (6 miles) in length and the water depth is generally less than 1.8 meters (6 feet). The main flow channel, which starts near the edge of sediment Deposit C, is approximately 2.4 meters (8 feet) deep on the south end and increases to approximately 5.8 meters (19 feet) near the outflow of the lake. Water depths outside the main channel and along the banks of the river are generally less than 1.8 meters (6 feet) deep (NOAA, 1992).

The Appleton to Little Rapids Reach is the longest reach of the river, extending approximately 32 km (20 miles). This reach meanders more than any other reach and is comprised of a series of large contiguous pools. Water depths in the main channel range between 1.8 and 3 meters (6 and 10 feet). Water depths in other areas of the reach vary from as little as 0.3 meter (1 foot) just downstream of Kaukauna to as great as 16 feet near the Rapide Croche dam. Between the Rapide Croche and Little Rapids dams, the river is generally narrow and main channel water depths are usually between 1.4 and 3.7 meters (8 and 12 feet).

The Little Rapids to De Pere Reach is approximately 10 km (6 miles) in length and the channel is relatively straight. The width is greatest at the upstream end and decreases downstream. The main channel depth is usually greater than 2.7 meters (9 feet) and increases to 5.5 meters (18 feet) approaching the De Pere dam. Along the banks of the river the water depths are generally less than 1.8 meters (6 feet).

Water depths in the De Pere to Green Bay Reach range between 1.8 and 7.3 meters (6 and 24 feet) in the main channel. This reach is approximately 11.3 km (7 miles) long and the lower 4.8 km (3 miles) of the reach are dredged by the U.S.

Army Corps of Engineers (USACE) in order to maintain a navigation channel. Prior to 1982, the navigation channel was maintained from the mouth of the river to the De Pere dam, but since 1982 this upper portion of the channel has been maintained to a depth of 1.8 meters (6 feet). Between De Pere and the Fort James-West turning basin (formerly Fort Howard), the depth of water is generally less than 1.8 meters (6 feet) outside of the navigation channel. Downstream of the Fort James-West turning basin, the river narrows so that the navigation channel almost encompasses the entire width of the river. The authorized navigation channel depth in this reach is 24 feet deep.

2.2.4 Lower Fox River Surface Water Hydrology

The slope of the bedrock and the pre-glacial bedrock valleys control drainage in the Lower Fox River valley. The Lower Fox River lies along the axis of a former bedrock valley which was filled with glacial and proglacial lake sediments. The Lower Fox River and its tributaries have flowed over and cut through these relatively flat glacial lake plain sediments.

Surface Water Flow Controls - Neenah-Menasha (Lake Winnebago)

Lake Winnebago is a highly controlled waterway with specific water level targets, depending on the season of the year. These controls influence flow in the Lower Fox River. The USACE oversees the Lake Winnebago flow controls and set specific water level targets to provide water usage for hydro power and navigation while preserving or enhancing fish, wildlife, wetland habitat, and water quality in the Lower Fox River and the Lake Winnebago pool. The local water level datum for Lake Winnebago is the Oshkosh datum.

Lake Winnebago seasonal water level targets have a range of less than 107 cm (3.5 feet) between the low (5.5 cm or 0.18 feet Oshkosh) and high (105 cm or 3.45 feet Oshkosh) water levels allowed under the plan. The water level targets are based on seasonal water level objectives. The regulation periods and objectives are briefly described below (USACE, 1998a).

Winter Drawdown. Following formation of solid ice cover in the Lake Winnebago pool, the water level is slowly lowered to the winter drawdown level of 21 cm (0.68 foot) Oshkosh. This drawdown level provides storage needed to contain spring runoff. Typically, drawdown commences at a rate designed to achieve a target level by about March 1.

Once the target drawdown level has been achieved, the stage is held constant until ice cover in the Lake Winnebago pool breaks up and starts moving out, which usually occurs in late March to early April. Following breakup of the ice, the Lake Winnebago pool is refilled. The target navigation stage, 91 cm (3.0 feet)

Oshkosh, is to be achieved by the beginning of May, typically the start of the navigation season.

Summer Navigation. During the navigation season (May to mid-October), the Lake Winnebago water level is held as close as possible to the target stage. However, since the year's lowest inflows occur during this time, it is not always possible to maintain the target level throughout the navigation season. When the navigation season ends, the water level in Lake Winnebago is decreased to approximately 61 to 76 cm (2.0 to 2.5 feet) Oshkosh by December 1. The only outflow constraint is to observe a maximum safe discharge of about 510 cubic meters per second (m^3/s) (18,000 cfs), while allowing only gradual changes in stage to minimize impacts on wildlife.

Lower Fox River Navigational Controls

There are 17 locks (Fox locks) and 12 dams located on the Lower Fox River between Lake Winnebago and the De Pere dam (Table 2-4). The Fox locks are an important aspect of navigation on the Lower Fox River. The Neenah and Menasha dams control flow out of Lake Winnebago, while the other 10 dams located between Little Lake Butte des Morts and De Pere control flow in the lower portion of the river. These dams control water levels and flow volumes throughout the river to provide a continued source of power for the hydroelectric plants associated with the dams and allow for navigation.

In 1984, the navigation portion of the Lower Fox River project was placed in "caretaker status" by the USACE. Under this status, the USACE performs minimal maintenance, and only three of the 17 navigation locks are in operational condition: the De Pere, Little Rapids, and Menasha locks. With the exception of the Rapide Croche lock (which is permanently closed to restrict the movement of sea lampreys), all the other locks would require maintenance and renovation before operational status can be restored.

The State of Wisconsin and the USACE signed a memorandum of agreement in September 2000 for the transfer of the Fox River locks from federal to state control. This agreement does not actually transfer the control or property yet, but it rather establishes the framework for the transfer to occur in the future. A number of general provisions of the agreement include the following:

- The Rapide Croche lock will be maintained as a sea lamprey barrier;
- The federal government will provide funding for the repair and rehabilitation of the land, locks, and appurtenant features prior to transfer;

- The locks and dams will be inspected to evaluate which features require immediate attention; and
- The State of Wisconsin will be responsible for the operation, maintenance, repair, replacement, and rehabilitation of the locks and appurtenant features after the transfer is complete.

Lower Fox River Surface Elevation

The Lower Fox River decreases about 48.2 meters (158 feet) between the Menasha dam and De Pere dam and approximately 51.5 meters (169 feet) between the Menasha dam and the mouth of the river. The overall gradient for the Lower Fox River is 51.5 meters (169 feet) over 63 km (39 miles) or 8.2×10^{-4} feet per foot (ft/ft). The river profile is shown on Figure 2-10.

Three areas exist where the water level elevation decline approaches or exceeds 9.1 meters (30 feet) between dams occurs largely within the Appleton to Little Rapids Reach, specifically in river stretches between the Appleton Upper and Appleton Lower dams, and between the Little Chute dam to the Rapide Croche dam. The gradients for each of these river sections is approximately an order of magnitude higher than the gradients for the remaining sections of the river. These three sections of the river contain limited soft sediment deposits because of increased flow velocities.

Measured and Estimated Stream Flow Velocities

Average stream flow velocity in each reach of the river has been estimated using discharge measurements collected from USGS gauges along the river (Table 2-5). These estimates were completed using the river cross-sections determined for the GBMBS modeling efforts (WDNR, 1995). Stream flow velocity is an important factor in evaluating areas where net sediment deposition is likely to occur. The overall Lower Fox River velocity average is just under 0.14 meters per second (m/s).

The average stream flow velocity in the Little Lake Butte des Morts Reach is just over 0.15 m/s (0.5 feet per second [ft/s]) and ranges from 0.08 to 0.35 m/s (0.26 to 1.15 ft/s). However, in Little Lake Butte des Morts proper, the average stream flow velocity is 0.13 m/s (0.42 ft/s) and ranges from 0.08 to 0.20 m/s (0.26 to 0.65 ft/s).

The average stream flow velocity in the Appleton to Little Rapids Reach is 0.24 m/s (0.78 ft/s), approximately 65 percent higher than the Little Lake Butte des Morts Reach and almost double the velocity found in Little Lake Butte des Morts

proper. This reach had the greatest estimated stream flow velocities, ranging from 0.15 to 0.37 m/s (0.48 to 1.23 ft/s).

In the Little Rapids to De Pere Reach, the average stream flow velocity is 0.12 m/s (0.40 ft/s); this is approximately half of the average velocity for the Appleton to Little Rapids Reach. Flow velocities in this reach range from 0.11 to 0.13 m/s (0.37 to 0.42 ft/s), which is the smallest variation in flow velocities noted in any reach.

The De Pere to Green Bay Reach has an average stream flow velocity of 0.08 m/s (0.25 ft/s); this is the lowest found in the entire river. Due to these overall low stream flow velocities, it is not surprising that the largest volume of deposited sediment is located in this reach (Section 2.3).

Low Flow and Flood Frequencies

The flow of the Lower Fox River has been monitored by as many as six stream gauging stations operated by the United States Geological Survey (USGS). The historical river discharge information from the Rapide Croche dam station (#04084500) is presented on Table 2-6. This gauging station recorded stream flow and discharge between October 1917 and September 1997. The water year (WY) extends from October 1 through September 30 of the following year.

The Rapide Croche results show that daily discharge volumes ranged from a low of 4 m³/s (138 cfs) to a maximum of 680 m³/s (24,000 cfs). According to the monthly results, following winter snowmelt and the generally heavy spring rains, April has the highest discharge volumes, while the late summer months of August and September generally have the lowest flows. These results are similar to the other Lower Fox River gauges. In addition, the results indicate that only 4 months, March through June, have average daily discharge volumes exceeding the annual average of 122 m³/s (4,300 cfs). Based on the 7-day average low stream flow with a 10-year frequency ($Q_{7,10}$), the low-flow value is 26.9 m³/s (950 cfs).

A similar flood frequency evaluation at the Rapide Croche gauging station was completed by USGS (Krug *et al.*, 1992). The results indicated that the 10-year flood discharge is 544 m³/s (19,200 cfs) while the 100-year flood flow is over 685 m³/s (24,200 cfs). These volumes are five to six times greater than the average discharge of 122 m³/s (4,300 cfs).

The Federal Emergency Management Agency (FEMA) mapped the 100-year flood elevation at the mouth of the Lower Fox River at 178.31 meters (585 feet) IGLD 1985 (FEMA, 1984). This is approximately 1.82 meters (6 feet) higher than the long-term average elevation of 176.485 meters (579.02 feet) IGLD 1985.

However, FEMA (1984) did not indicate what the flow rate was for this 100-year flood event (National Flood Insurance Program, 1984).

2.2.5 Green Bay Bathymetry

The bathymetry in Green Bay is controlled by its geologic history. Based on the eastern dip of the bedrock units along its lengthwise axis and the glacial scouring of the basin, the bay gently slopes to mid-bay moving from west to east. Eastward of this mid-bay, the bottom is a relatively flat sediment plain that rises abruptly near the east shore. Within this framework, the bathymetry for each Green Bay zone has unique characteristics. The bathymetry for the De Pere to Green Bay Reach (Zone 1) has been described above. The bathymetry of Zone 2 is more complicated than the bathymetry of either Zone 3 or Zone 4, due to the numerous shallow areas located within Zone 2. Zones 3 and 4 generally represent a large, relatively deep body of water which only have areas with depths less than 9 meters (30 feet) located along the shoreline (Figure 2-9).

The bathymetry of Zone 2 is generally shallow, with all water depths less than 8 meters (26.5 feet). From the mouth of the Lower Fox River to a line connecting Long Tail Point/Point Sable (the Lower Green Bay AOC), water depths range from 0.3 to 3.4 meters (1 to 11 feet), excluding the navigation channel (Figure 2-9). Water depths at the very southern end of Green Bay are extremely shallow and generally less than 1.5 meters (5 feet). The navigation channel lies almost entirely within Zone 2. The navigation channel extends approximately 18.8 km (11.7 miles), from the mouth of the Lower Fox River to a line from Dyckesville (on the east shore). The depth of the navigation channel is maintained between 6.25 and 7.16 meters (20.5 and 23.5 feet), while water depths in Zone 2 are generally less than 3.7 meters (12 feet) over much of this area.

There are a number of spits, shoals, and other shallows located in Green Bay that are prominent physical features of the bathymetry. Many of the shoals/shallows are associated with the tributaries, predominantly located along the west side of the bay. In Zone 2, these shallow areas are expressed as the island chains and points extending from the west shore out into the bay. Long Tail Point is located just south of the Suamico River mouth while Little Tail Point is located just south of the Little Suamico River (Figure 2-9).

The depth of water in Zone 3 is generally greater than 10 meters (30 feet). Water depths in Zone 3 range from about 12.5 meters (41 feet) at the boundary between Zones 2 and 3 to 33.5 meters (110 feet) just west of Chambers Island, near the boundary between zones 3 and 4. The deepest part of Zone 3 is located just southeast of Green Island where water depths of 34.4 meters (113 feet) have been measured.

Large portions of Zone 4, from Chambers Island to just south of Big and Little Bays de Noc, have water depths exceeding 9.1 meters (30 feet). However, in the vicinity of Big and Little Bays de Noc, the water depths decrease and shallow areas with water depths less than 9.1 meters (30 feet) are predominant. Similar to Zone 3, the depth gradient on the east side of the bay is up to one order of magnitude greater than the gradient on the west side of the bay. The deepest point in the bay is 53 meters (176 feet) deep, located about 6.4 km (4 miles) west of Washington Island.

Green Bay-Lake Michigan Passages

The four main passages connecting Green Bay with Lake Michigan are: 1) Porte des Morts Passage; 2) Rock Island Passage; 3) St. Martin Island Passage; and 4) Poverty Island Passage. The Porte des Morts Passage is approximately 2.3 km (1.4 miles) wide and water depths in the passage range as deep as 39.3 meters (129 feet). The Rock Island Passage is approximately 3.9 km (2.4 miles) wide and water depths range as deep as 46.6 meters (153 feet). The passage is narrow due to the presence of the St. Martin Island Shoal, which extends south of St. Martin Island. The St. Martin Island Passage is located between St. Martin Island and a number of small islands and shallows, including Gull, Little Gull, and Gravelly islands, as well as the Gravelly Island Shoals (Gull/Gravelly Island complex). This passage is only approximately 2 km (1.2 miles) wide and water depths range as high as 36.3 meters (119 feet). Finally, Poverty Island Passage is located between the Gull/Gravelly Island complex and Poverty Island. This passage is approximately 3.4 km (2.1 miles) wide and water depths range up to 26.5 meters (87 feet). No significant waterway passage is located north of Poverty Island.

2.2.6 Green Bay Surface Water Hydrology

Green Bay Water Level Elevations

Green Bay water level elevations are controlled by and related to the water level in the Lake Michigan-Huron basin. These two lakes are connected through the Straits of Mackinac and are treated as a single lake basin. Water levels within the Great Lakes are measured according to the International Great Lakes Datum (IGLD 1985) which has its zero reference elevation point located at Rimouski, Quebec, Canada.

The overall annual long-term average (LTA) elevation for the Lake Michigan-Huron basin is 176.49 meters (579.02 feet) IGLD 1985 (USACE, 1996). The monthly LTA elevation ranges from a low of 176.34 meters (578.54 feet) IGLD 1985 in February to a high of 176.64 meters (579.53 feet) IGLD 1985 in July (USACE, 1998b). Historically, the lowest and highest monthly water elevation

levels were recorded in March 1964 and October 1986, and the basin has an overall range of approximately 1.92 meters (6.3 feet).

Water levels within the Great Lakes are currently dropping. Between March 1999 and February 2000, only 68 percent of the normal annual precipitation fell in the Lake Michigan-Huron basin. In addition, snowmelt runoff is responsible for about 40 percent of the annual water supply into the Great Lakes. In March 2000, the snow-water equivalent was less than 10 cm (4 inches) throughout Michigan and Wisconsin. In addition to less snowfall, the warmer winters of 1998, 1999, and 2000 have reduced ice cover over the lakes and increased evaporation. Combined, these factors have contributed to lake levels which are approaching the record low for the Lake Michigan-Huron basin (USACE, 2000b).

Green Bay Water Circulation, Currents, and Mixing Patterns

Green Bay has complex water currents and circulation patterns. However, there is an overall general counterclockwise movement of water in the bay. Water from Lake Michigan moves into the bay and south along the west shore. Water from the Fox River is generally transported north along the east shore of the bay, carrying suspended sediment as well as contaminants in dissolved and particulate phases. In addition, the inner bay and outer bay each have their own general counterclockwise currents (or gyres), which are affected by the presence of spits and shoals on the west side of the bay.

HydroQual, Inc. completed modeling analysis of current patterns in Green Bay using 1989/90 GBMBS data. A 3-dimensional circulation model calculated the monthly mean surface and bottom circulation patterns for August 1989. Based on modeling results, it was estimated that monthly average residual currents exceeding 5.0 cm/s were common in most of the bay during August 1989 (Blumberg *et al.*, 2000).

Water circulation in Green Bay is controlled by a number of different factors: 1) surface water elevation changes induced by wind and barometric pressure; 2) wind speed and direction; 3) river discharge; 4) upwelling of the thermocline in Lake Michigan; 5) thermal and density gradients between the bay and Lake Michigan; 6) ice cover and; and 7) the Coriolis effect.

Long-term averaging of Green Bay currents reveals steady, residual circulation patterns responsible for the net mass transport of suspended solids. The monthly averaging of currents shows a relatively consistent circulation pattern, with the magnitude of the currents varying from month to month. Figures 2-12 and 2-13 show the formation of several gyres in the bay, resulting in a complex residual

circulation pattern in Green Bay. This circulation pattern affects mixing, flushing, and mass transport.

The formation of so many small-scale gyres, in both the inner and outer bays, causes localized entrapment of water masses and associated constituents. Due to the localized gyres, the flushing time for Green Bay is estimated to be on the order of 1,000 days. Estimated flushing times for the inner portion of Green Bay are much lower than for the entire bay. The areas within 10 and 25 km of the mouth of the Lower Fox River flush in about 25 and 100 days, respectively (Mortimer, 1978).

Lower Fox River Discharge into Green Bay

The USGS acoustic velocity meter (AVM) located at the mouth of the Lower Fox River records the river discharge into Green Bay. The Lower Fox River is the largest tributary to Green Bay, contributing approximately 42 percent of the total drainage, over 95 percent of the PCB load, and 70 percent of the suspended sediments (WDNR, 1999a; Smith *et al.*, 1988). The average discharge is 122 m³/s (4,300 cfs). However, water levels in the bay cyclically rise higher than levels in the river and flow is reversed, affecting the De Pere to Green Bay Reach of the river. This reversal in flow is due to wind-induced increases in water levels (seiche effect) and a small lunar tide. A seiche is produced when northeast winds push water to the south end of the bay. Water levels in this end of the bay can increase as much as 0.9 meter (3 feet), although the fluctuation often ranges between 0.15 and 0.3 meter (0.5 and 1 foot). The seiche occurs daily and, as evidenced by the AVM data, results in reversed stream flows in the lower reach of the river. The flow reversal can be significant, with recorded velocities exceeding 92 m³/s (3,250 cfs) on a daily basis and even greater flow reversal recorded for individual storm events. The seiche also produces a counterclockwise flow in Green Bay, which facilitates mixing of the river and bay water nutrient loads.

Lower Fox River Plume Studies

Water entering Green Bay from the Lower Fox River is typically warmer and more sediment-laden than the rest of the bay water, thus allowing the Lower Fox River plume to be tracked within the bay. Studies conducted since the late 1960s of the Lower Fox River plume show that river water moves up the east shore of the bay. The plume has been observed and detected up to 40 km (25 miles) from the mouth of the river (Gottlieb *et al.*, 1990).

The Lower Fox River plume was also discernible in the water column by higher chloride and higher conductivity measurements. A plume with higher chloride and conductivity concentrations extended from the river mouth along the east shore of the bay for a distance of approximately 42 km (26 miles), which is

consistent with other observations. A plume of lower-conductivity water was also detected along the western shore of the inner bay and was ascertained to be outer bay or Lake Michigan water moving south along the western shore.

The plume studies show that Long Tail Point, which begins about 6 km (3.7 miles) north of the river mouth on the western side of the bay, forms a mixing barrier in the southernmost portion of Green Bay. This barrier allows Lower Fox River water to move farther up the bay before becoming thoroughly mixed with other water. The August 1989 surface and bottom water currents (Figures 2-11 and 2-12) indicate that northward flow occurs immediately adjacent to the east shore of the bay, from the mouth of the river to about the location of Little Sturgeon Bay. North of Little Sturgeon Bay, the flow patterns become much more varied and complicated (Lathrop *et al.*, 1990).

Inner Bay/Outer Bay Mixing Studies

Chambers Island is the boundary between inner and outer Green Bay. Flow around Chambers Island is an important aspect of circulation in Green Bay. Previous studies have found that net flow is from the inner to outer bay and that most of the flow from the inner to outer bay occurs along the eastern side of Chambers Island.

Currents. Water flow around Chambers Island is more complex than a simple counterclockwise motion. During the summer months, the colder, deeper water tends to flow south into the inner bay on the west of Chambers Island, and the shallow, warmer water layer flows north out of the inner bay on both the west and east sides. These results are shown on Figures 2-11 and 2-12. During the summer, surface currents are stronger east of the Oconto River, with two clockwise gyres between the Oconto and Menominee Rivers. These gyres merge along the northern shore, downstream of the Peshtigo River and the combined surface currents are then directed northeast towards Washington Island (Blumberg *et al.*, 2000). Around Chambers Island, surface currents are clockwise northwest of the island and counterclockwise southeast of the island (Figure 2-12). In addition, the formation of many small-scale gyres causes localized entrapment of water masses and their constituents, implying that the mass crossing the Chambers Island transect is not directly transported to the mouth of Green Bay and into Lake Michigan (Miller and Saylor, 1993).

During the winter, water tends to flow north out of the inner bay on the east side of the island and the eastern half of the western passage. These flow patterns result in a lesser, separate counterclockwise flow pattern in both the inner and outer bay.

Water Exchange. Water exchange between the inner and outer bays has a net outward flow of approximately $130 \text{ m}^3/\text{s}$ (4,591 cfs). Current velocities were greatest east of Chambers Island, sometimes ranging as high as 0.35 m/s (1.1 ft/s). West of Chambers Island, the velocities typically range from 0.12 to 0.24 m/s (0.4 to 0.8 ft/s). Current velocities in the inner bay typically range up to 0.12 m/s (0.4 ft/s) (Miller and Saylor, 1993).

Sediment Transport. Approximately 17,500 metric tons (MT) (19,290 tons) of sediment were transported from the inner bay to the outer bay, generally along the east side of Chambers Island, between May and October 1989. Approximately 19,900 MT (21,940 tons) of sediment were transported from the outer bay to the inner bay along the west side of Chambers Island (Hawley and Niester, 1993). Therefore, there was a net increase of approximately 2,400 MT (2,650 tons) of sediment transported into the inner bay. However, as bay sediments are often subjected to a repeating cycling of suspension-transport-deposition, movement of sediment between the inner and outer bays may occur a number of times before sediment is ultimately transported further north into the bay and Lake Michigan.

Green Bay/Lake Michigan Mixing Studies

The exchange of water between Green Bay and Lake Michigan is highly variable and complex. The four main channels connecting Green Bay and Lake Michigan are: Poverty Passage, Porte des Morts Passage, Rock Island Passage, and St. Martin Island Passage, and are described in the Green Bay bathymetry section.

Large volumes of water consistently move between the bay and the lake through the Porte des Morts and Rock Island passages. Currents measured in the passages connecting Green Bay with Lake Michigan typically ranged from 0.12 to 0.30 m/s (0.4 to 1.0 ft/s). The estimated flow into the bay is approximately $3,300 \text{ m}^3/\text{s}$ (116,540 cfs or 871,000 gallons per second). In 1992, the estimated water volume exchange between the bay and the lake was about $3,500 \text{ m}^3/\text{s}$ (123,600 cfs).

Warm water leaves the bay in the upper portion of the water column while cold water enters the bay in the lower part of the water column (Figures 2-11 and 2-12). August 1989 modeling results suggest that warm surface water (epilimnetic) flow from Green Bay to Lake Michigan was about $3,000 \text{ m}^3/\text{s}$ (105,940 cfs), while cold bottom water (hypolimnetic) flow to the bay was about $2,870 \text{ m}^3/\text{s}$ (101,350 cfs). This resulted in a net outflow of about $130 \text{ m}^3/\text{s}$ (4,590 cfs) from the bay. These results indicate that the exchange of water between Green Bay and Lake Michigan is much greater than any other source of water into or out of the bay (Miller and Saylor, 1985; Blumberg *et al.*, 2000).

The estimated precipitation input to the bay is 105 m³/s, tributary input is 336 m³/s, and evaporation loss is 87 m³/s. These values are all at least an order of magnitude less than the estimated exchange between Green Bay and Lake Michigan.

2.2.7 Green Bay and Lower Fox River Ice Cover

The Port of Green Bay is closed to shipping from January 1 through March 31 due to ice cover (Haen, 2000). Although the port is officially closed for this 3-month period, ice cover in the bay is usually present from early to mid-December through mid- to late April (Gottlieb *et al.*, 1990).

Ice cover in Green Bay initially occurs over the shallowest water areas of the inner bay as well as both Bays de Noc. Ice typically begins forming loose, open pack-ice floes in these areas in early to mid-December, as temperatures usually range from -10 to -4 degrees centigrade (°C) (14 to 24 degrees Fahrenheit [°F]). During December, the ice slowly consolidates from loose pack to a solid ice sheet covering the shallowest areas and slowly expanding. During January, which has the coldest average temperatures, ice cover within the bay usually ranges from 95 to 100 percent. Depending upon seasonal conditions, open-water areas usually form in the outer bay in late January and February. This occurs first in and around the passages connecting Green Bay with Lake Michigan and along the east side of the outer bay (due to the counterclockwise currents) because Lake Michigan water is generally about 1 to 2 °C warmer than water within Green Bay. Additionally, water from the Green Bay tributaries is generally the coldest water within the bay, due to the fact that the formation of frazil ice within the river can cool water temperatures below 0 °C (32 °F).

Frazil ice is composed of small ice crystals that form in turbulent water. Due to the water movement, the ice crystals flow within the water and act to super-cool the water to temperatures below 0 °C (32 °F). The ice does not solidify until the water movement slows or until the water comes in contact with solid objects that slow the current velocity. Therefore, frazil ice can cause difficulties with intake structures and pier/dock structures located along the rivers or bay, where it is present. Additionally, as the water flows from the rivers into the bay, current velocities decrease and ice forms rapidly.

Ice thickness in the Lower Fox River averages 12 to 24 inches thick from year to year and may occasionally measure greater than 36 inches thick (Paulson, 2000; Boronow, 2000). Many areas of the lower reaches and near dams/drops remain open with flowing water year-round. The pools above the dams usually freeze over solid (Boronow, 2000). Flowing water and temperature influence ice

thickness from year to year in addition to snowfall, rainfall, and snowpack conditions.

In either late January or February, open-water areas usually form in the outer bay, especially in and around the passages connecting Green Bay with Lake Michigan and along the east side of the outer bay. This occurs because Lake Michigan water is generally about 1 to 2 °C warmer than water within Green Bay and it reflects the influences of the generally counterclockwise currents.

2.2.8 Total Organic Carbon

Total organic carbon (TOC) affects the bioavailability and toxicity of some substances and influences the composition and abundance of benthic communities. Some chemicals (particularly low-solubility organic compounds) strongly adsorb onto organic coatings over the surfaces of inorganic particles. As a result, sediment with high TOC content tends to accumulate higher concentrations of organic compounds than sediment with lower TOC content. TOC was analyzed in over 1,600 sediment samples from the Lower Fox River, Green Bay, and select tributaries to assist in the interpretation of the sediment organics data. TOC concentrations in sediments are extremely variable.

Average TOC value in Lake Winnebago is 7.8 percent (78,000 milligrams per kilogram [mg/kg]), suggesting that significant background TOC levels are present within the system. Moving downstream, the TOC average in each reach shows a general decline. The river-wide TOC average is 4.91 percent. The average TOC concentrations in Green Bay range from 0.14 to 2.33 percent. In comparison, the Lake Michigan TOC average is 0.35 percent.

2.2.9 Other Physical Parameters

Percent solid results indicate that solids generally comprise approximately 40 percent of the sediment samples analyzed. The average values for all three of the reaches upstream of the De Pere dam range from 37 to 42 percent. However, individual values have a much greater range; between 18.1 and 88.2 percent. The results indicate that the nature of the material changes significantly throughout each river reach and individual deposits may require additional characterization prior to implementation of selected remedial alternatives. The average result in Green Bay is 44 percent; similar to the river. However, in Green Bay Zone 4, the average solid result is approximately 70 percent, indicating that sediments in this portion of the bay are much more likely to consist of coarse-grained sands rather than fine-grained silt/clay.

The average dry bulk density results range from 0.31 to 1.18 grams per cubic centimeter (g/cm³). The average results for each reach range between 0.51 and

0.66 g/cm³, while the river-wide average is 0.55 g/cm³. These results are lower than the average dry bulk density for soils of 1.3 to 1.35 g/cm³.

Wet bulk density and specific gravity results are available for only a few deposits/SMUs. Wet bulk density results give an indication of how much the mass of the material will change once sediments are removed from the river (e.g., during remedial efforts). The wet bulk density results ranged from 1.15 to 1.23 g/cm³ with an average of 1.17 g/cm³. The moisture content was also calculated as part of the bulk density determinations and the water content (mass) generally comprises approximately 50 to 75 percent of the sediment sample mass. Specific gravity results ranged from 2.32 to 2.59, with an average value of 2.46.

2.2.10 River and Bay Sediment Dredging

Due to the expansive areas of sediments that have accumulated downstream of the De Pere dam and out into the southern end of Green Bay, the USACE periodically dredges the navigation channel. The original navigation channel extends from Lake Winnebago out into Green Bay approximately 18.8 km (11.7 miles). However, the USACE currently only dredges and maintains the navigation channel in Green Bay and as far upstream as the Fort James turning basin, which is located approximately 5.5 km (3.4 miles) upstream of the mouth of the river. The remaining portions of the navigation channel, along with the lock and dam system, have been placed in a caretaker status.

The only dredging records available for the Lower Fox River (above the De Pere dam) since 1957 indicate that approximately 9,900 m³ (12,950 cubic yards [cy]) were dredged from the Menasha Channel and Neenah Harbor in 1965 and 1968, respectively.

USACE records below the De Pere dam and for Green Bay indicate that over 12.1 million m³ (15.9 million cy) have been dredged from the navigation channel since 1957. According to the dredging records, on average, approximately 282,350 m³ (369,300 cy) of sediment are removed from the channel annually. Between 1957 and 1965, approximately 2.8 million m³ (3.7 million cy) of sediment were disposed of at open-water locations. The primary open-water sediment disposal areas were located in the vicinity of the former Cat Island Chain and on the north side of the shoal extending from Point Au Sable to Frying Pan Island (Figure 2-9). The Bay Port CDF was opened in 1965 and has served as the primary disposal facility for navigation channel sediments. Almost 7.3 million m³ (9.4 million cy) have been placed in the Bay Port CDF and, according to Dean Haen (Haen, 2000), the facility still has capacity for another 1.5 million m³ (2 million cy) of sediment. The Kidney (Renard) Island CDF opened in 1979 and received over 2 million m³ (2.7 million cy) of sediment. The last year this CDF received

sediments was 1996. Since its closure, the CDF has a navigation channel depth of 20.5 to 23.5 feet.

2.3 Soft Sediment Thickness

The soft sediment thickness of river sediments is generally from 1 to 2 meters thick (3 to 6.5 feet) while some of the larger deposits can range up to 3.28 meters (10.76 feet) thickness (Table 2-1). The thickest deposits are located in the De Pere to Green Bay Reach, with sediment thickness ranging up to 5.8 meters (19 feet) near the turning basin (Montgomery-Watson, 1998).

2.3.1 Calculation of Thickness

During the early portion of the 1989/1990 sampling efforts, sediment thickness was measured to a maximum depth of 1.06 meters (3.5 feet). Greater sediment thicknesses were subsequently noted in some deposits from later studies and these results are included in the database. The maximum depths from which PCB samples were collected in each deposit/SMU group, as well as in each bay zone, are listed in Table 2-7. If these depths were greater than 1.06 meters (3.5 feet), then the maximum sediment thickness of these deposits was changed to match the PCB sampling depth. In some areas, no sediment thickness data was collected because either: 1) PCBs were not detected in these areas, or 2) results of poling data showed no soft sediment was present. Sediment thickness contours were primarily dependent on Option 1.

2.3.2 Mapping the Occurrence of Sediment

Interpolated grids were developed for the presence or absence of sediment in the Lower Fox River and Green Bay. Sediment occurrence grids, also called sediment thickness contour maps, for the Lower Fox River were developed from field measurement of sediment thickness (Figures 2-5 through 2-8). The occurrence of sediment was interpolated separately for all nine depth layers on the Lower Fox River. If the thickness at a sampling location was less than half the layer thickness, then the area was designated as not containing sediment. Using this approach, sediment was also absent in deeper layers because the sample depth did not extend to the modeled depth (e.g., if a sample was collected from 0 to 50 cm, then the interpolation results indicate that there is no sediment in the 50- to 100-cm layer).

For Green Bay, the occurrence-of-sediment grid was developed from the GBMBS using a 5,000-meter (16,400-foot) by 5,000-meter (16,400-foot) grid. Based on sampling results, each grid cell was determined to be either soft sediments or glacial till (no soft sediments present). Grid cells that were not sampled were assigned to either the soft sediment or glacial till categories based on professional judgement, which included consideration of adjacent cells where sampling

occurred and the depositional environment. For instance, areas near the mouth of the Lower Fox River that were not sampled were considered to contain soft sediment, as this is a depositional zone for sediments from the river. The 5,000-meter (16,400-foot) grid was translated into a 100-meter (328-foot) grid to match the sediment interpolation grids and allow a direct overlaying of the different grids.

2.4 Nature and Extent of Chemicals of Concern

The Screening Level Risk Assessment (SLRA) identified chemicals of potential concern (COPCs) in the Lower Fox River and Green Bay which included: PCBs, dioxins/furans, DDT (and its metabolites), dieldrin, arsenic, lead, and mercury (RETEC, 1998). The Baseline Risk Assessment (BLRA) concluded that the chemicals of concern (COCs) were PCBs, mercury, and DDE (RETEC, 2002b). The COCs represent potential risks to human and ecological receptors as described in Section 3. Although PCBs are the primary focus of the FS, all three compounds (PCBs, mercury, DDE) are carried forward in the FS.

2.4.1 Historical Sources of Chemicals of Concern in the Lower Fox River

Polychlorinated Biphenyls (PCBs)

From the early 1950s through early 1970s, the manufacture of carbonless copy paper used a PCB emulsion. In 1954, Fox River valley paper mills began manufacturing carbonless copy paper and PCBs were released to the environment through manufacture, de-inking, and recycling of carbonless paper. Aroclor 1242 was the PCB mixture used in the manufacture of carbonless copy paper and approximately 45 million pounds of this emulsion were reportedly used in the Lower Fox River valley between about 1954 and 1971. The use of PCBs was unregulated and their potential health effects were unknown during this time period.

The use of PCBs in carbonless paper manufacturing ceased in 1971. WDNR (1999a) estimated that approximately 313,600 kg (691,370 pounds) of PCBs were released to the environment during this time, although the discharge estimates range from 126,450 to 399,450 kg (278,775 to 880,640 pounds) based on the percentages of PCBs lost during production or recycling of carbonless copy paper. Further, WDNR (1999a) estimated that 98 percent of the total PCBs released into the Lower Fox River had occurred by the end of 1971. In addition, WDNR (1999a) indicated that five facilities, including the Appleton Papers-Coating Mill, P. H. Glatfelter Company and associated Arrowhead Landfill, Fort James-Green Bay West Mill (formerly Fort Howard), Wisconsin Tissue, and Appleton Papers-Locks Mill, contributed over 99 percent of the total

PCBs discharged to the river. A portion of these PCBs settled into river sediments.

The companies discussed above have been named as potentially responsible parties (PRPs) under the CERCLA statute. Fort James Corporation, P. H. Glatfelter, Riverside Paper Company, U.S. Paper Mills Corporation, and Wisconsin Paper Mills, Inc. were identified as PRPs by the U.S. Fish and Wildlife Service in 1994, and NCR Corporation and Appleton Papers, Inc. in 1996. This group calls itself the Fox River Group (FRG).

Point source discharges of the COPCs have decreased significantly since implementation of the Clean Water Act and other environmental regulations in the early 1970s. As a result, input of PCBs into the Lower Fox River from regulated discharges is essentially eliminated. However, residual sources for PCBs and other detected compounds remain in the river sediments, which continue to affect water quality, fish, wildlife, and potentially humans. PCBs have also been detected in many fish and bird species in the Lower Fox River and Green Bay. Due to the continued elevated levels of PCBs present within the Lower Fox River and Green Bay, WDNR issued consumption advisories in 1977 and 1987 for fish and waterfowl, respectively; Michigan issued fish consumption advisories for Green Bay in 1977. Most of these advisories are still in place.

Sediments are the most significant source of PCBs entering the water column and over 95 percent of the PCB load into Green Bay is derived from the Lower Fox River. PCBs from sediment deposits are discharged into Green Bay at the mouth of the Lower Fox River through sediment transport and PCB dissolution in the water column. Up to 280 kg (620 pounds) of PCBs were transported from the Lower Fox River into Green Bay during a 1-year period in 1989–1990. Approximately 122 kg (270 pounds) of PCBs are transported from Green Bay to Lake Michigan annually. Based on the data included in the Fox River database, the estimated mass of PCBs in sediments of the Lower Fox River and Green Bay is approximately 100,000 kg (220,000 pounds).

Mercury and DDE

Sediments from upstream of the Kaukauna dam to Green Bay contain elevated mercury concentrations. Elevated mercury levels in Lower Fox River sediments are attributed to mercuric slimicides (phenyl mercuric acetate) used in paper manufacturing. This practice was discontinued in 1971. Studies completed in the 1990s indicate that mercury concentrations remain elevated more than 20 years after mercury use was discontinued (WDNR, 1996).

Few identifiable point sources exist for the other compounds of potential concern in the Lower Fox River. The pesticides DDT and dieldrin once had widespread use in agriculture, but there is no point source associated with these compounds. However, DDE in sediments below the De Pere dam and Green Bay are of risk to fish and birds. Similarly, the metals lead and arsenic, even now, have widespread uses and are not associated with any specific point sources.

2.4.2 PCB Distribution in Sediments

This section discusses: 1) data interpolation methods for determining PCB spatial distributions, 2) occurrence of sediment, 3) PCB sediment volume and mass distribution, and 4) riverbed maps showing the occurrence of PCBs in the sediments of the Lower Fox River and Green Bay. These bed maps were prepared from surface and subsurface sediment profile data contained within the Fox River database (FRDB) and originating at specific points along the river and in the bay. Specific details of the bed mapping procedure may be found in the Remedial Investigation Report (RETEC, 2002a). The distribution of PCBs in sediments within each river reach and zone of Green Bay are illustrated on Plates 2-1 through 2-5.

Data Interpolation for the Lower Fox River

In order to view the spatial distribution of PCBs across the study area, a methodology was developed to predict, or interpolate, sediment concentrations between known data collection points. An interpolation grid was necessary to resolve discrepancies between samples with different detection limits, depth intervals, and sample collection and compositing methods from numerous studies conducted over a 10-year period. From the interpolated PCB concentration points, a map of the overall concentrations as sediment isopleths was produced. The methodology for mapping property distributions was developed jointly by WDNR and the Fox River Group. Sediment bed properties and bed mapping are further discussed in the RI Report.

The interpolations for the Lower Fox River are based on the results included in the FRDB as of March 1, 2000, consisting of about 900 sample results and locations in the Lower Fox River from nine studies conducted between 1989 and 1999. The 1999 data set included post-dredge sampling data from the Deposit N sediment removal demonstration project.

Data for the Lower Fox River were first screened to remove older data that were geographically too close to locations with newer data. Sediment data for the Lower Fox River has been collected in various studies since 1989. In order to use the most recent data available, the data were assigned to three different time periods: 1989 through 1992, 1993 through 1995, and 1996 through 1998. All

of the data from the period 1996 through 1998 were used in the interpolation. A relationship was developed between similar ranges of PCB concentrations and the distances between data points in each range. From this analysis, a distance of less than 133 meters (436 feet) was determined to indicate that an older sample location was too close to a newer sample location. In this case, the older data were not used in the interpolations. This analysis was conducted first on the 1993 through 1996 data set to create a new data set for the 1993 through 1998 period. The analysis was then repeated using the 1989 through 1992 data set. In this way, the entire data set from 1989 through 1998 was used, but older data were superceded by newer data.

The interpolation used the revised 1989 through 1998 data set. The entire area of the Lower Fox River was superimposed with a square grid containing cells 10 meters by 10 meters. The screened data were used to interpolate the parameter value at each grid point.

Interpolations used the inverse distance method, whereby grid point values were more strongly affected by the sampling location(s) closest to the grid point. The inverse distance method gives more weight to closer points by using an inverse distance to the fifth power, meaning that points farther away have significantly less effect on the interpolated value at a point. For instance, for two data points, where the first point is half as far from the grid point as the second point, the first point contributes 32 times more to the interpolation than does the second point.

In addition to inverse weighting, a maximum set distance was selected for which data points may influence grid point results. Erroneous interpolations can occur if data are extrapolated over excessive distances. To prevent this condition, grid point values were computed using data within a certain distance or radius of the grid point location. Data points located further from the grid point than the established radius were not used in the interpolation. If there were no data points within the interpolation radius of a grid point, then no value was interpolated for that grid point.

The interpolation radius for computing sediment thickness was set at 100 meters. For all other parameters, the interpolation radius varied among the river reaches. In the Little Lake Butte des Morts Reach, complete coverage of the river required that a radius of 400 meters (1,312 feet). For the Appleton to Little Rapids Reach, the river is more narrow and linear. For this reach, the interpolation radius was computed as one-third of the average river width, or 79 meters (259 feet), to minimize the influence of separate deposits on the interpolation. The Little Rapids to De Pere and De Pere to Green Bay reaches used an interpolation radius

of 1,000 meters (3,280 feet), as specified in Technical Memorandum 2e and Technical Memorandum 2e Addendum (WDNR, 1999b, 2001).

Data interpolations for the Fox River were conducted for nine different layers of sediment depth: 0 to 10, 10 to 30, 30 to 50, 50 to 100, 100 to 150, 150 to 200, 200 to 250, 250 to 300, and greater than 350 cm. These sediment depths were selected based on previous and current modeling efforts as well as being defined by WDNR (1999b).

Data Interpolation for Green Bay

Interpolation of sediment data from Green Bay followed the same methods as used in the Lower Fox River. The data set for the Green Bay interpolations included approximately 240 sample results and locations from 3 studies conducted between 1989 and 1998.

For the interpolation, Green Bay was divided into a square grid with 100 meters between points. The same inverse distance approach was used on both the Lower Fox River and Green Bay, but the analysis on Green Bay used the distance squared rather than distance raised to the fifth power. Therefore, interpolated results in Green Bay were more affected by data points farther away from the grid point than in the Lower Fox River interpolation. For instance, for two data points, where the first point is half as far from the grid point as the second point, the first point contributes four times more to the interpolation than does the second point.

The maximum interpolation radius for Green Bay was set at 8,000 meters (26,250 feet). This means that data points more than 8,000 meters (26,250 feet) from a grid point were not used in the interpolation for that grid point. Conversely, grid points more than 8,000 meters (26,250 feet) from any data point have no interpolated value, and this is evidenced by the lack of data in some areas of the bay, particularly along the west shore of Zone 3A and in Zone 4.

Green Bay data were integrated for four different layers of sediment depth: 0 to 2, 2 to 10, 10 to 30, and greater than 30 cm. In addition to these four sediment layers, a composite sediment layer was developed for a thickness of 0 to 10 cm. This layer was computed as a thickness-weighted average of the 0- to 2- and 2- to 10-cm layers. The 0- to 10-cm composite layer was developed for use in the RA and food web modeling. The other two layers were selected to coincide with layering developed for the river.

Occurrence of Sediment

The occurrence-of-sediment grids were used to edit the PCB concentration grids. This was necessary because the PCB interpolation could not identify areas where sediment was absent. Without an overlay of sediment thickness, PCB concentrations could be interpolated into areas that do not contain sediment. By using the occurrence-of-sediment grids, the PCB interpolation was restricted to those areas where sediments are present.

PCB Sediment Volume and Mass Distribution

The interpolated grids provided a means of computing the volume of contaminated sediment and the mass of PCB in the Lower Fox River and Green Bay (Tables 2-1 and 2-2). Each grid point represents a grid cell with an area 10 meters (33 feet) by 10 meters (33 feet) in the Lower Fox River and an area 100 meters (330 feet) by 100 meters (330 feet) in Green Bay. The sediment volume at each grid cell in a layer was computed as the area of grid cell multiplied by the layer thickness. The volume within a layer above some PCB concentration was estimated by summing the number of grid points above the PCB concentration and multiplying by the area of a grid cell and the thickness of the layer. The grid points were also counted within a river reach, deposit/SMU area, or Green Bay zone to determine the volume of contaminated sediment within an area of the river or bay. The estimated volume of sediments with PCBs will be discussed for each reach or zone below.

Mass calculations were computed in a manner similar to the volume calculation. The mass was computed by multiplying the sediment volume by the bulk density and the PCB concentration at a grid cell. Summing the mass over the grid cells within a reach, deposit/SMU, or zone yielded the mass of PCB within that area of the river or bay. The estimated mass of PCBs will be discussed for each reach or zone below.

PCB Bed Maps

Maps showing the distribution of PCBs in sediment were constructed directly from the interpolated grids using GIS ArcView and Spatial Analyst. The methods used to produce these maps were the same as those outlined in Technical Memorandum 2e, the Addendum to Technical Memorandum 2e, and Technical Memorandum 2f (WDNR, 1999b, 2001, 2000b, respectively). The interpolated grid was displayed and color contoured into different ranges based on PCB concentration. Areas where sediment is absent were not included in the color contouring. Similarly, areas outside the interpolation radius were not included in the color contouring. The concentration intervals selected for the bed maps were based upon a combination of observed concentration ranges, cleanup level evaluations, the 50 ppb PCB detection limit, variability of data collection, and

criteria for bed mapping. The total PCB concentration ranges and mapping intervals used for the Lower Fox River and Green Bay (in micrograms per kilogram [$\mu\text{g}/\text{kg}$]) are:

- 0 to 50,
- 50 to 125,
- 125 to 250,
- 250 to 500,
- 500 to 1,000,
- 1,000 to 5,000,
- 5,000 to 10,000,
- 10,000 to 50,000,
- Greater than 50,000 (Lower Fox River), and
- Greater than 5,000 (Green Bay).

Sediment bed maps for total PCBs are shown on Plates 2-1 through 2-5, and are discussed below.

2.4.3 Extent of PCB Chemical Impacts

Approximately 96,800 kg (213,400 pounds) of PCB in the Lower Fox River and Green Bay system are distributed in about 474 million m^3 (620 million cy). Review of the PCB mass and contaminated sediment volume herein considers sediments which contain more than 50 $\mu\text{g}/\text{kg}$ PCB. The results are summarized below and indicate that the De Pere to Green Bay Reach and Green Bay Zone 2, combined, contain almost 60 percent of the total PCB mass in the system in less than 10 percent of the total contaminated sediment volume. The PCB mass and volume of contaminated sediment for each river reach and bay zone are listed in Table 2-7.

As shown in Table 2-7, over 96 percent of the total PCB mass within the Lower Fox River and Green Bay is located between the De Pere dam and the northern boundary of Zone 3, which is bounded by Chambers Island. The magnitude and extent of PCB-impacted sediments for each river reach and zone of Green Bay are summarized below.

Little Lake Butte des Morts Reach

The nine sediment deposits in this reach (deposits A through H and POG) contain about 1,540 kg (3,395 pounds) of PCBs in about 1.35 million m^3 (1.77 million cy) of sediment with concentrations greater than 50 $\mu\text{g}/\text{kg}$ PCB (Plate 2-1). These deposits cover about 314 hectares (775 acres) and thicknesses range up to approximately 1.9 meters (6.2 feet) thick. The highest detected total PCB concentration in sediment was 222,722 $\mu\text{g}/\text{kg}$ (average 15,043 $\mu\text{g}/\text{kg}$). Upstream

deposits A, B, and POG have the highest PCB mass to volume ratios in this reach. These three deposits contain 952 kg (2,100 pounds) of the PCBs in about 252,000 m³ (329,600 cy) of sediment. About 910 kg (2,000 pounds) of the PCBs in these three deposits is present in the upper 100 cm (3.28 feet) of sediment. Deposits A/B, E, and POG contain over 1,400 kg (3,086 pounds) of PCBs, or about 91 percent of the PCBs present in this reach. About 53 percent of the mass in the deposits listed above are present in the upper 30 cm (1 foot) of sediment.

Appleton to Little Rapids Reach

Sediment accumulation in the Appleton to Little Rapids Reach is more localized compared with the other three reaches. The 22 sediment deposits in this reach (deposits I through DD) contain about 94 kg (207 pounds) of PCBs in about 184,790 m³ (241,700 cy) of sediment, with concentrations greater than 50 µg/kg PCBs (Plate 2-2). These deposits cover approximately 153 hectares (378 acres) and generally occur in areas of slower stream flow velocities (e.g., where the river widens, in the vicinity of dams/locks, eddy pools along the banks, etc.). Sediment thicknesses range up to approximately 100 cm (3.23 feet) thick. The highest detected total PCB concentration in sediment was 77,444 µg/kg (average 6,406 µg/kg). Only deposits W, X, and DD have a volume exceeding 30,000 m³ (39,240 cy) of sediment and these are located where the river widens and/or upstream of a dam. The average sediment volume in each of the remaining 19 deposits in this reach is about 3,780 m³ (4,944 cy). Approximately 32 kg (71 pounds) of PCBs remain in deposits N and O following completion of the 1999 sediment remediation demonstration project, and no future attempt to remove this mass is currently under consideration. The total surface area of this reach is approximately 7,000,000 m² while deposits with measurable PCBs are only 870,000 m² (12.6 percent). In general, surface sediment PCB concentrations are less than 1,000 µg/kg in this section.

Little Rapids to De Pere Reach

Sediment accumulation in this reach extends over a long distance and large area. The four sediment deposits in this reach (deposits EE through HH) contain 980 kg (2,160 pounds) of PCBs in approximately 1.71 million m³ (2.24 million cy) of sediment with concentrations greater than 50 µg/kg PCB (Plate 2-3). The four deposits in this reach are essentially a single sediment unit covering about 266 hectares (657 acres). Sediment thicknesses range up to 2.3 meters (7.5 feet) thick in select areas, especially near the De Pere dam. The highest detected total PCB concentration in sediment was 54,000 µg/kg (average 6,292 µg/kg). Concentrations exceeding 5,000 µg/kg exist at the southernmost limit to Deposit EE, and at the northernmost part of the reach behind the De Pere dam. Almost

all of the PCBs are contained in the upper 100 cm (3.28 feet) of sediments, with 535 kg (1,180 pounds) contained in the upper 0 to 30 cm (0 to 1 foot).

De Pere to Green Bay Reach (Green Bay Zone 1)

This reach contains the largest volume and areal extent of impacted sediments in the Lower Fox River (Plate 2-4). Ninety-one (91) percent of the PCB mass for the entire river is present in this reach. The 96 SMUs in this reach contain 25,984 kg (57,285 pounds) of PCBs in over 5.5 million m³ (7.2 million cy) of sediments with concentrations greater than 50 µg/kg PCB (Plate 2-4). Almost the entire sediment bottom contains soft sediment covering about 524 hectares (1,295 acres) and ranging in thickness up to 4 meters (13 feet). The highest detected total PCB concentration in sediment was 710,000 µg/kg (average 21,722 µg/kg) before the completion of SMU 56/57 demonstration project.

Approximately 636 kg (1,400 pounds) of PCB and 31,000 m³ (40,550 cy) of sediment were removed from SMUs 56–61 during the SMU 56/57 sediment remediation demonstration project. Further, removal of additional sediment and PCBs from SMU 56/57 started in August 2000, but the final mass and volume estimates are not expected to be known until early 2001. Excluding SMUs 56–61, six SMU groups (SMUs 20–25, 32–37, 38–43, 62–67, 78–73, and 80–85) contain almost 11,000 kg (24,250 pounds) of PCBs, or about 37 percent of the total mass in the Lower Fox River. These SMU groups also exhibit the highest PCB concentrations or greatest PCB mass to sediment volume ratios in the river.

The mass of PCBs increases significantly with depth. Approximately 16,150 kg (35,530 pounds) of PCBs, or about 55 percent of the total PCB mass in the Lower Fox River, occurs in the upper 100 cm (3.28 feet) of sediment. Approximately 10,600 kg (23,370 pounds) of PCBs (36 percent of the PCBs in the river) are buried below 100 cm (3.28 feet).

PCBs are fairly evenly distributed in the surface sediments within this reach. Of the 5,210,000 m² of sediment surface within this reach, 4,500,000 m² (87 percent) have PCB concentrations greater than 1,000 µg/kg.

Green Bay Zone 2

This zone contains approximately 32,000 kg (70,550 pounds) of PCBs in 39.5 million m³ (51.6 million cy) of sediment with concentrations greater than 50 µg/kg (Plate 2-5). Sediments with the highest PCB concentrations have accumulated adjacent to the navigation channel and between the mouth of the river and Point Au Sable. The PCB distribution reflects the influence of Green Bay current patterns, as higher concentrations are located along the east side of the bay. Sediments in Zone 2A cover about 5,930 hectares (14,650 acres) and

have an average thickness of about 0.34 meter (1.1 feet). In Zone 2B, the sediments cover about 5,150 hectares (12,725 acres) and have an average thickness of about 0.38 meter (1.25 feet). The highest total PCB concentration in sediment was 17,000 $\mu\text{g/kg}$ (average 324 $\mu\text{g/kg}$).

Considering only sediments with more than 1,000 $\mu\text{g/kg}$ PCBs reduces the mass and volume estimates to 27,470 kg (60,430 pounds) and 17.8 million m^3 (23.3 million cy). This represents slightly more than 45 percent of the PCBs, but less than 3 percent of the estimated volume of impacted sediment in the bay.

Approximately 14,500 kg (31,900 pounds) of PCBs are contained in about 29.8 million m^3 (39 million cy) of sediment in the upper 30 cm (1 foot). Sediments with the highest PCB concentrations have accumulated adjacent to the navigation channel and between the mouth of the river and Point Au Sable. The distribution shows the influence of Green Bay current patterns, as higher PCB concentrations are located along the east side of the bay.

Green Bay Zone 3

This zone contains approximate 35,240 kg (77,700 pounds) of PCBs in approximately 397 million m^3 (519 million cy) of sediment with concentrations greater than 50 $\mu\text{g/kg}$ (Plate 2-5). PCB distribution results show that sediments with the highest concentrations have accumulated along the east shore of Green Bay, extending from Dyckesville to Egg Harbor, reflecting the influence of Green Bay current patterns. Sediments in Zone 3A cover about 85,890 hectares (212,240 acres) and have an average thickness of just 0.21 meter (0.7 foot). In Zone 3B, the sediments cover about 69,340 hectares (171,340 acres) and have an average thickness of about 0.31 meter (1 foot). The highest detected total PCB concentration in sediment was 1,320 $\mu\text{g/kg}$ (average 448 $\mu\text{g/kg}$) in Zone 3B.

Considering sediments with more than 1,000 $\mu\text{g/kg}$ PCBs reduces the mass and volume estimates to 1.65 kg (3.64 pounds) and 8,800 m^3 (11,510 cy), respectively. This represents less than 0.003 percent of both the PCB mass and sediment volumes in the bay.

Considering the upper 30 cm (1 foot) of sediments, approximately 30,000 kg (66,000 pounds) of PCBs are contained within about 355.9 million m^3 (465.5 million cy). However, as indicated above, a large majority of this mass is located in sediments with concentrations below 1,000 $\mu\text{g/kg}$ PCBs. Surface sediment PCB concentrations are generally higher in the southern part of the zone (greater than 500 $\mu\text{g/kg}$), and lower (less than 125 $\mu\text{g/kg}$) just below Chambers Island.

Green Bay Zone 4

The estimated PCB mass and sediment volume results indicate that Zone 4 is relatively unaffected by PCBs compared to zones 2 and 3. However, fewer soft sediment locations were noted and sampled in this zone than in either zones 2 or 3 during 1989 and 1990 sampling activities. Zone 4 contains less than 925 kg (2,040 pounds) of PCBs, or only about 1 percent of the total mass in the system. Total PCB concentrations detected in sediment within Zone 4 are all less than 500 $\mu\text{g/kg}$ (average 54 $\mu\text{g/kg}$).

Findings regarding the presence and distribution of other COPCs identified in the Screening Level Risk Assessment are fully described in the Lower Fox River and Green Bay RI Report (RETEC, 2002a).

2.4.4 Extent of Other COPC Impacts

Major findings regarding the distribution of other chemical parameters in sediments include:

- Mercury was used in a number of pulp and paper production activities to reduce slime. The SLRA identified mercury concentrations exceeding 0.15 mg/kg as a potential concern. Mercury concentrations in Lake Winnebago sediments averaged 0.14 mg/kg while average concentrations in each reach of the Lower Fox River ranged from 1.26 to 2.42 mg/kg. The elevated mercury concentrations are widespread in the Lower Fox River sediments and are not associated with any specific deposit or point source discharge.
- Mercury concentrations in Green Bay are much lower than levels in the river. The average concentration in Zone 2 was 0.593 mg/kg, but averages in zones 3 and 4 range only up to 0.19 mg/kg, which is just above the Lake Winnebago background concentration.
- The spatial distribution of dioxin/furan compounds cannot be evaluated because only 22 samples were collected from deposits D/E/POG, deposits EE/HH, and SMUs 56/57. Concentrations of 2,3,7,8-TCDD/TCDF detected in sediments ranged from 0.23 to 170 nanograms/kilogram (ng/kg) (parts per trillion [ppt]).
- Sixteen (16) chlorinated pesticides, generally associated with agricultural non-point source activities, were detected in river sediments at concentrations up to 67 $\mu\text{g/kg}$. Additional non-point pesticide sources may include atmospheric deposition and stormwater runoff from pesticides used at parks, golf courses, and other institutional

facilities; however, these sources are likely to be small compared with agricultural activities. Only seven compounds, DDT, DDD, DDE, endrin aldehyde, endrin ketone, gamma-BHC (lindane), and heptachlor, were detected in more than four sediment samples. Distribution of these compounds was generally sporadic. Only DDT and dieldrin were identified by the SLRA as being chemicals of potential concern. The SLRA identified DDT (total) concentrations above 1.6 $\mu\text{g/kg}$ as a potential concern. DDT was detected at 10 widely-distributed locations within the Lower Fox River above this concentration. There is no established concentration of concern for dieldrin, which was detected in only one sample from Little Lake Butte des Morts, suggesting that dieldrin distribution is very limited. Neither DDT nor dieldrin were detected within Green Bay.

- Lead is a naturally-occurring element in soil and sediment. Background lead concentrations in Lake Winnebago sediments averaged 35 mg/kg while average concentrations in each reach of the Lower Fox River ranged from 75.6 to 167.8 mg/kg. The SLRA identified lead concentrations above 47 mg/kg as a potential concern. While some deposits detected lead concentrations as high as 1,400 mg/kg, lead occurrence is widespread in the Lower Fox River sediments and cannot be related to any specific point source discharge. In Green Bay, the average lead concentration ranged from 1.5 to 29.9 mg/kg, which is lower than the Lake Winnebago background concentration.
- Arsenic is also naturally occurring in soil and sediment. Background arsenic concentrations in Lake Winnebago sediments averaged 5.33 mg/kg. The SLRA identified arsenic concentrations above 8.2 mg/kg as a potential concern. An elevated arsenic concentration was detected in only one location (SMU 38) at 385 mg/kg. Excluding this arsenic detection, average concentrations in both the river and the bay were below the Lake Winnebago background concentration of 8.2 mg/kg.
- SVOCs, which result from both point and non-point sources in urban and rural areas, were detected throughout the Lower Fox River at concentrations exceeding the background levels observed in Lake Winnebago. The SVOCs detected at higher concentrations included PAHs and also occurred in widespread areas of the river. Total PAH concentrations below 4,000 $\mu\text{g/kg}$ typically do not warrant further assessment. Total PAH concentrations along the Lower Fox River ranged non-detectable to 60,000 $\mu\text{g/kg}$. A number of locations from Little Lake Butte des Morts to the mouth of the river exceeded 4,000

$\mu\text{g/kg}$ with the highest values frequently observed downstream of more urbanized areas. None of the sediments samples collected within Green Bay Zone 2 exceeded 4,000 $\mu\text{g/kg}$, and PAHs were not detected in zones 3 or 4.

2.5 Chemical Fate and Transport

Chemical fate and transport in the Lower Fox River and Green Bay is largely a function of suspension, deposition, and redeposition of the chemicals of concern that are bound to sediment particles. The organic compounds of potential concern, including PCBs and pesticides, exhibit strong affinities for organic material in the sediments. The suspension and transport of these compounds absorbed onto the sediments is largely controlled by moving water in the Lower Fox River and Green Bay. Greater volumes of sediments become suspended and are transported during high-flow events (such as storms and spring snowmelt). The Lower Fox River has an average discharge of 122 m^3/s (9,605 cfs) 10 percent of the time. Previous investigators have estimated that these high-flow events transport more than 50 to 60 percent of the PCB mass which moves over the De Pere dam and into Green Bay.

Other modes of contaminant transport such as volatilization, atmospheric deposition, and point source discharges are negligible when compared to the river transport. Figures 2-13 and 2-14 each present a conceptual model of PCB fate and transport in the Lower Fox River and Green Bay system by TSS load and PCB mass, respectively. Total suspended solids (TSS) loads are from the Fox River into Green Bay and are summarized on Table 2-8.

2.5.1 Lower Fox River Sediment Deposition

Sediment deposition and resuspension processes are primarily a function of particle size and water velocity. Transport of sediments occurs as particles are suspended in the water or moved along the base of the river as bed load. The system is dynamic and areas of sediment accumulation may become erosional areas, or vice versa, based on changes in water velocity (e.g., storm events), river bathymetry (e.g., shoreline erosion) and other factors.

TSS data have been evaluated to estimate the movement of sediment through the system. Distinct deposits of accumulated sediment occur throughout the Lower Fox River in areas of low stream flow velocity. These areas are generally in the vicinity of the locks, dams, shoreline coves and back eddies, or in areas where the river widens. However, estimates of net deposition or net erosion only reflect an average accumulation or loss over time for an entire reach and do not explain finer-scale deposition/erosion events occurring within a reach. Net deposition does not imply a purely depositional environment and vice versa.

Over 75,000 MT (82,700 tons) of TSS enters Little Lake Butte des Morts from Lake Winnebago annually. However, the TSS load at the Appleton gauging station is lower than this figure by approximately 8,000 MT (8,800 tons). Based on the net loss of TSS load, the slow water velocity, shallow bathymetry, and extensive sediment deposits, the Little Lake Butte des Morts Reach is subject to sediment accumulation.

The Appleton to Little Rapids Reach experiences a net loss of sediment. Between Appleton and Kaukauna, the river shows a marginal increase of approximately 2,500 MT (2,750 tons) in the TSS load. However, between Kaukauna and Little Rapids, the river experiences a net erosion as the TSS load doubles from approximately 70,000 MT (77,000 tons) to approximately 142,000 MT (154,000 tons) (Figure 2-13). The lack of soft sediment between Rapide Croche dam and Little Rapids suggest that resuspended sediments are likely transported to Little Rapids (Deposit DD) or further downstream. Based on the net increase of TSS load, the fast stream velocities (as high as 0.3 m/s), the narrow river sections, and the lack of many sediment deposits, the Appleton to Little Rapids Reach is subject to a net loss of sediment.

The TSS load within the Little Rapids to De Pere Reach declines by about 61,500 MT (68,000 tons), a 43 percent decrease from upstream inputs. Deposit EE, the largest sediment deposit upstream of the De Pere dam, extends approximately 8.5 km (5.3 miles) upstream of the dam. Based on the significant net decrease of TSS load, the large number of sediment deposits, and the slow stream flow velocities (average of 0.12 m/s), the Little Rapids to De Pere Reach experiences net sediment deposition and accumulation.

In the De Pere to Green Bay Reach, TSS loads coming over the De Pere dam range between approximately 80,000 and about 100,000 MT (90,000 and 110,000 tons) annually. At the river mouth, the TSS load was only 20,000 MT (22,000 tons), indicating that the TSS load declined by approximately 75 to 80 percent. The average stream flow velocity in this reach was less than 0.08 m/s, which is the lowest value for any of the four river reaches. Results of the Green Bay Mass Balance Study show that at a typical discharge rate of 105 m³/s (3,700 cfs), approximately 272 MT (300 tons) per day of TSS flows over the De Pere dam; however, only approximately 54 MT (60 tons) per day are discharged at the mouth. Based on the significant net decrease of TSS load, the large number of thick sediment deposits, and the slow stream flow velocities, the De Pere to Green Bay Reach experiences net sediment deposition.

For storm events with flows around 280 m³/s (9,900 cfs), the TSS load over the De Pere dam increases to 1,800 MT (2,000 tons) per day, while storm events with

flows of 430 m³/s (15,250 cfs) have a TSS load of about 7,100 MT (7,850 tons) per day. Quadrupling the stream flow rate in the river results in an approximately 26 times greater TSS load.

2.5.2 Green Bay Sediment Deposition

Estimated annual sediment accumulation in Green Bay varies from about 20,000 MT to about 150,000 MT (22,050 to 165,350 tons). The USGS estimated the average annual sediment load from the Fox River into Green Bay is approximately 82,500 MT (90,940 tons) to 136,000 MT (150,000 tons). Recent 1998 data suggests that about 153,000 MT (168,800 tons) of sediment were discharged into the bay during 1998.

Sediment is not deposited uniformly across the bottom of the bay. Water current patterns determine the distribution of sediments, and ultimately, that of PCBs and other chemical compounds in Green Bay. The primary depositional zone in Green Bay extends along the east shore of the bay for a distance of approximately 25 km (15.5 miles) north of the Lower Fox River mouth.

Approximately 17,500 MT of sediment is transported from the inner bay to the outer bay along the east side of Chambers Island. However, about 19,000 MT of sediment is transported from the outer bay to the inner bay along the west side of the island, following dominant circulation patterns (Figures 2-11 and 2-12). Therefore, there is a net sediment gain in the inner bay of approximately 2,400 MT. Approximately 10 to 33 percent of the inner bay tributary sediment load (the majority of which is from the Lower Fox River) is transported to the outer bay.

Sediments that have been deposited can be re-entrained and transported. A number of different studies and models have evaluated sediment resuspension, and it has been shown that most sediment transport within the bay occurs during large storms. A large volume of sediment was transported from the inner bay to the outer bay as a result of a September 1989 storm. Erosion of shore and nearshore sediments was found to be directly related to the magnitude, direction, and duration of winds within the bay, which effected currents and wave action. Within the bay, sediment deposits are located in areas where the stress ratios were less than about five to nine, in comparison with the Lower Fox River ratios of three to five. Sediments within the bay settle in a far less turbulent environment than those of the Lower Fox River; therefore, the uppermost layer of sediment was found to have consolidated in 7 to 14 days, rather than less than 3 hours. Moderate to strong winds, which are the single most important factor for bay sediment resuspension, occur on average every 7 days on the Great Lakes.

2.5.3 PCB Transport

Review of sediment transport through the river reaches and bay zones was evaluated to assess where PCB transport is occurring with all movement. The conceptual models show the PCB mass/volume contained with each reach/zone (greater than 50 $\mu\text{g/kg}$ PCB) and how much PCBs are transported from one reach/zone into the next annuli (Figures 2-13 and 2-14).

Fox River

Approximately 1,540 kg of PCBs are present within the Little Lake Butte des Morts Reach. The sediments of the lake have long acted as a continuing source of PCBs to the river/bay system. WDNR (1995) estimates are that less than 1 kg per year is annually transported from Lake Winnebago into Little Lake Butte des Morts (Figure 2-14). Approximately 40 kg of PCBs are resuspended and transported from Little Lake Butte des Morts to the Appleton to Little Rapids Reach, even though Little Lake Butte des Morts is a net depositional area.

The Appleton to Little Rapids Reach exhibits increased stream flow velocities compared with the rest of the river. Stream flow velocity in this reach averages about 0.283 m/s, which is more than twice the entire river average of 0.137 m/s. Only about 94 kg of PCBs are located within sediments in this reach. These data show that little of the sediment or PCBs are deposited permanently within this reach.

Within the Little Rapids to De Pere Reach, the De Pere dam acts as a sediment trap. Approximately 64 kg per year of PCBs enter the reach and 77 kg per year are transported over the De Pere dam. Although net sediment deposition occurs in this reach (Figure 2-13), dissolution of PCBs from sediment into the water column becomes more important than does actual transport of sediment to which PCB is sorbed. Stream flow velocities downstream of the Little Rapids dam decrease to approximately 0.122 m/s, which is below the river average of 0.137 m/s.

The De Pere to Green Bay Reach has the greatest PCB mass and volume of sediment within the Lower Fox River (over 25,900 kg of PCB). Over 90 percent of the PCB mass and 60 percent of the PCB-impacted sediment present in the Lower Fox River are located within this reach. The average stream flow velocity in this reach is approximately 0.077 m/s, well below the river average of 0.137 m/s. This low river velocity accounts for the high volumes of sediments deposited within this reach. Although approximately 80,000 MT TSS flows over the De Pere dam, only about 20,000 MT TSS (about 25 percent) is transported passed the river mouth and into the bay. On a mass and volume basis, this reach has the

most significant sediment load in the river. Sediments in this reach act as the major continuing source of PCBs into Green Bay.

Green Bay and Lake Michigan

Based on river water sample results, approximately 220 to 280 kg (484 pounds) of PCBs were transported from the Lower Fox River into Green Bay annually in 1989/90 and 1994/95. These results suggested that roughly one percent of the PCB mass within the river is discharged into the bay annually. However, recent 1998 data suggest that the PCB load into Green Bay may be decreasing and only about 125 kg of PCBs were discharged from the river into the bay based on the 1998 data, which is just over 0.4 percent of the river mass. The average estimates of the PCB mass entering Green Bay from the Lower Fox River annually range between 125 and 220 kg per year. Based on peak flow conditions within the river, the highest estimated PCB load into Green Bay is about 550 kg per year. Approximately 120 kg of PCBs are transported from Green Bay into Lake Michigan annually (Figure 2-14). However, the results of these studies suggest that the PCB mass located between the De Pere dam (in the Lower Fox River) and Chambers Island (in Green Bay) is so large that, at these low rates of loss, a large mass of PCBs will remain in these sediments far into the future.

Other PCB Pathways

In addition to PCB input to the river and bay from contaminated sediments, other PCB sources and sinks exist. Approximately 3 to 5 kg of PCBs are introduced into the river from other discharge locations where PCBs remain in effluent lines or from continued carbonless paper recycling. Due to the ubiquitous and resilient nature of PCBs, low concentrations of PCBs have been detected at discharge locations that continue to contribute PCBs to the system. Estimates of atmospheric deposition of PCBs into Green Bay range from 2 to 35 kg annually. Based on a 1987 and 1988 USGS PCB mass-loading study of major tributaries into Green Bay, more than 90 percent of the PCB load into Green Bay was attributable to the Lower Fox River. The other Green Bay tributaries contributed only about 10 kg annually to the bay (Figure 2-14).

In addition to accumulation of PCBs in river and bay sediments, PCBs do exit the system through volatilization (Figure 2-14). A number of studies have indicated that PCB volatilization from the water exceeds atmospheric deposition. PCB losses through volatilization to the atmosphere ranges between 0 and 5 kg/yr for the Lower Fox River, whereas volatilization losses in Green Bay range between 130 and 500 kg annually. The surface area for Green Bay is a significant volatilization pathway.

2.6 Time Trends of Contaminants in Sediment and Fish

A time trends analysis was conducted on sediments and fish tissue within the Lower Fox River and Zone 2 of Green Bay in order to assess whether statistically significant changes in PCB concentrations were occurring. For the purposes of the BLRA, it was important to understand if apparent or implied decreases in PCB concentrations in sediments and fish tissue were real, and if so, determine if the rate of change could be estimated. A brief description of the methods and results is given below. The detailed analysis may be found as Appendix B of the Remedial Investigation Report (RETEC, 2002a).

2.6.1 Sediment Methods

For sediments, the overall approach was to first review the data for usability, then explore relevant groupings of the data both horizontally and vertically to conduct regression-type analyses for increases or decreases in PCB concentrations over time. All data used in these analyses were from the Fox River database.

Exploratory analysis demonstrated that PCB concentrations varied across locations in the river. To adequately conduct the analysis of time trends, it was necessary to undertake a separate evaluation of the spatial layout; a horizontal evaluation within the river bed and a vertical evaluation with each depth stratum. The deposit designations used in the RI/FS (e.g., A, POG, EE, or SMU 26, shown on Figures 2-1 through 2-4) were found to be unsuited to defining spatially-cohesive subsets, many samples had no deposit designation and some deposit designations spanned stretches of a river reach too long to allow adequate assessment and control of spatial structure. Based upon analysis of the spatial layout, 23 distinct geographic “deposit groups” were determined, forming data subsets with spatial structures far more amenable to statistical analysis. These were given designations that reflected the general deposit designations in the RI/FS, with the added benefit that these groups designated non-overlapping spatial sets. The statistical groups analyzed are shown on Figures 2-15 through 2-17.

Depth strata within each deposit group were consistent with the RI/FS: 0 to 10 cm (0 to 4 inches), 10 to 30 cm (0.33 to 1 foot), 30 to 50 cm (1 to 1.6 feet), 50 to 100 cm (1.6 to 3.3 feet), and 100+ cm (3.3+ feet). Sample groups defined by a specific deposit and depth stratum were analyzed separately for the time trends. Depth strata within some deposits were excluded due to either inadequate sample size or lack of time variation. After averaging samples from a common sediment core within a particular stratum, 1,618 observations in 46 combinations of deposit and depth were included in the sediment time trends analysis. PCBs were

analyzed as the logarithm of PCB concentration (in $\mu\text{g/kg}$) due to the approximately lognormal distribution of these values.

Spatial correlation among observations was determined using semivariograms, a common technique in geostatistics. In order to avoid overstating statistical significance of time trends in the presence of spatially-correlated observations, the Window Subsampling Empirical Variance (WSEV) (Heagerty and Lumley, 2000) estimation method was used. WSEV is analogous to averaging observations within cells of a grid, where the grid size is specified such that sample subsets falling into different cells of the grid are approximately independent of each other. The WSEV method yields a proper estimate of variance that can be used to calculate statistical significance.

The WSEV method for handling spatial dependence was used in conjunction with a standard method for estimating time trends; regression analysis. Regression models for log PCB concentration versus time, depth, and linear and quadratic spatial coordinates were fitted using the method of maximum likelihood, which readily incorporates the observations below detection limit without imputation of a value such as half the detection limit. Throughout the analysis, significance levels of $p < 0.05$ from regression analysis or from any other analysis were designated as “statistically significant.”

2.6.2 Fish Methods

Like sediments, the approach for examining time trends in fish tissue PCB concentrations was to first review the data, then explore relevant groupings of the data on which to conduct regression-type analyses. In addition to the four reaches of the Lower Fox River, fish time trends were examined in Green Bay Zone 2. This was undertaken to determine whether PCB exposure in Zone 1 and Zone 2 were identical (i.e., represent a single exposure unit), or if there were distinct trends in these two zones for the target fish species. Fish tissue data from those two zones were explored first to ascertain whether they represented a single or separate exposure units (i.e., have different time trends for PCBs). This was conducted to determine whether the data should be combined for a single analysis, or to conduct separate time trends analyses for the two zones.

All data used in these analyses were from the Fox River database. A total of 1,677 fish samples were available for analysis, divided into three main sample types: fillet without skin, fillet with skin, and whole body. Inadequate sample size presented the greatest obstacle to analysis. There were several cases where there were substantial data, but there was inadequate spread in the years between collections. It should be noted that within the Little Rapids to De Pere Reach, there were no fish groups with both sufficient sample size and time spread. There

were over a hundred combinations of reach, species, and sample type with at least one observation, but only 19 of these had sufficient numbers of samples and a sufficient time spread for analysis of time trends. Carp and walleye provided the largest number of observations of any species. These 19 combinations represent 867 samples—over half of all samples of whole body, fillet with skin, and fillet without skin. In addition to the 19 combinations, there were 4 analyses which could statistically combine samples from the fillet and whole body categories (within a single reach and single species) to come up with a single time trend estimate.

Data on PCBs in fish were analyzed as the logarithm of PCB concentration in micrograms per kilogram. The percent lipid content of samples was significantly associated with PCB concentration in most species and sample types, and was thus used as a normalization term in all analyses.¹

Regression models for PCB concentrations versus time were fitted using the logarithm of percent lipid content and time as independent variables. A linear spline function was included in some time trends analyses to accommodate different rates of change in PCB concentrations during earlier versus later periods. The maximum likelihood method was used to accommodate observations below detection limit. A test for changing trends was also carried out.

The difference in fish PCB concentrations between Green Bay Zone 1 (De Pere to Green Bay Reach) and Green Bay Zone 2 was analyzed using both cross-sectional data (five analyses) and time trends data (three analyses), again controlling for percent lipid content of samples in regression models. All regression models for the fish analysis were fitted using the maximum likelihood method to accommodate the small fraction of observations below the detection limit.

2.6.3 Time Trend Results

Results of the sediment time trends are presented in Table 2-10, and are represented graphically on Figures 2-15 through 2-17. Seventy percent of all calculated slopes (32 out of 46) were negative. However, only 13 out of the 46 slopes were statistically significant, such that a hypothesis of no change in PCB

¹ Note that fish concentrations of PCBs were not normalized by dividing by lipid content of samples. Thus, the concentrations are expressed as log micrograms of PCBs per kilogram of tissue rather than per kilogram of lipid.

concentration over time could be rejected. Of those, 10 were negative,² and within that subset eight were in the 0- to 10-cm (0- to 4-inch) segment.

Conducting a meta-analysis on the surface sediment data showed a negative trend in all reaches except Appleton to Little Rapids. A meta-analysis of time trends in surface sediments yielded an average rate of decrease in PCB concentration per year of -18 percent in Little Lake Butte des Morts, +0.6 percent in the Appleton Reach, -10 percent in the Little Rapids Reach, and -15 percent in the De Pere Reach. These trends were statistically significant except for the Appleton Reach.

While those data suggest an overall decline in PCBs in the Lower Fox River, a more careful analysis of the subsurface data suggest that these declines are restricted to the upper 0 to 10 cm (4 inches). While 32 out of the 46 analyses were negative, there is a strong trend toward fewer and weaker negative slopes at increasing depth. Table 2-10 and Figures 2-15 through 2-17 show in general that the subsurface deposits do not significantly decline in sediment PCB concentrations. For Little Lake Butte des Morts, the figures suggest that there is a generally increasing trend in subsurface PCBs, and an indeterminate mixture of trends that is not distinguishable from zero in the Appleton and De Pere reaches. For Little Rapids to De Pere, there are consistently negative trends in the 10- to 30-cm (0.33- to 1-foot) strata, but in the lower strata, the data are consistent with either zero trend (30 to 50 cm [1 to 1.6 feet]), or an increasing trend (50 to 100 cm [1.6 to 3.3 feet]).

These results suggest that over time, the surface sediment concentrations of PCBs have been steadily decreasing. However, numerically this was difficult to define, and depended upon the specific deposits or sediment management units. PCB concentrations in sediment suggest declines, but a large fraction of analyses provided little useful trend information. A large fraction of sediment analyses yielded imprecise or inconclusive trends such that positive, negative, or zero trends are consistent with the data.

Like sediment PCB concentrations, fish tissue PCB concentrations showed a significant but slow rate of change throughout the lower Fox River and lower Green Bay (Table 2-11). Initial exploration of the data demonstrated that there were statistically significant declines in tissue PCB concentrations in all species in all reaches. More detailed analyses were then conducted to determine if there had been a constant linear rate of decline, or if significant changes in the rate of decline, or “breakpoints,” could be identified. Among fish time trends analyzed,

² A negative slope indicates decreasing PCB concentrations; a positive slope indicates increasing PCB concentrations over time.

9 out of 19 combinations of reach, species, and sample type showed a statistically significant change in slope during earlier and later periods. In all of the reaches of the river, and in Zone 2, there were steep declines in fish tissue PCB concentrations from the 1970s, but with significant breakpoints in declines beginning around 1980. After the breakpoint, depending upon the fish species, the additional apparent declines were either not significantly different from zero, or were relatively low (5 to 7 percent annually). However, for two species there were increases in PCB concentrations after the breakpoint; walleye in Little lake Butte des Morts and carp in Green Bay Zone 1.

Most slopes were negative, and all statistically significant slopes were negative. Over the period of analyzed data, percentage rates of decrease were usually between -5 and -10 percent per year (compounded). Percent lipid content of tissue was significantly related to PCB concentration in 16 out of the 19 analyses. Specific trends in sediment and fish by reach are discussed below.

Little Lake Butte des Morts

Time trend results for sediments in Little Lake Butte des Morts are presented in Table 2-10 and on Figures 2-15 through 2-17. With the exception of two strata at 10 to 30 cm (0.33 to 1 foot) in two separate deposit groups, slopes are negative (9 out of 11 analyses). However, statistically significant negative slopes (decreasing PCB concentration over time) was found only in surface sediments (0 to 10 cm [0 to 4 inches]) of four deposit groups (AB, D, F, GH). The estimated rates of decrease ranged from 8 to 24 percent per year, with wide confidence intervals for these rates of change; a rate of decrease of as little as 1 to 5 percent and as much as 15 to 43 percent per year. While the slopes were negative, there were no significant trends at deposits C or POG. In fact, for POG the estimated annual slope was -18.6 percent per year, but the upper and lower confidence bound on the estimate ranged from -43.3 to +16.9 percent per year.

When pooled across all deposits, there was an estimated significant ($p < 0.001$) average annual decrease of -15 percent of surface concentrations within the period supported by the data. It is important to note that on a reach basis, the 95 percent confidence intervals around the estimated average were 22 percent, up to 8 percent annual rate of decrease.

The only statistically significant increasing trend of PCB concentrations occurs at 10 to 30 cm (0.33 to 1 foot) in Deposit Group D, where the rate of increase is 108 percent per year. The confidence interval for the significantly increasing slope at 10 to 30 cm (0.33 to 1 foot) in Deposit Group D indicates a rate as low as 59 percent and as high as 171 percent per year. The Time Trends Analysis Report noted that this must represent a temporary positive trend because a

projection of the PCB concentration even at the minimum of 59 percent per year would yield an absurd 10,000-fold increase in PCB concentration after 20 years.

Caution needs to be used in the interpretation of the estimated average decrease within this reach. As noted previously, there were wide confidence intervals around all estimates for the sediment deposit groups. While the mass-weighted time trend for surface sediments indicated a significant decrease, the fact that the estimate did not include Deposit E, the largest depositional area within the reach, must be considered. There were insufficient data to conduct the analysis for Deposit E, and thus the sediment time trend is somewhat skewed by the lack of inclusion here.

For the fish examined in this reach, an early rapid decline was observed until around 1987, followed by either a slower decline or a flattening without further decline, depending upon the species (Table 2-11). Within this reach, time trends were conducted on carp and walleye (skin-on fillet and whole body), and northern pike and perch (skin-on fillet). For carp, the breakpoints identified for the skin-on fillet and whole body were 1979 and 1987, respectively. Walleye data fillet and whole body data show that the breakpoint occurs between 1987 and 1990. The fillet data suggests no change in concentration after the breakpoint, while the whole body data showed a sharp rate of increase (22 percent per year). However, the latter analysis, when tested, was not significantly different from zero. For northern pike skin-on fillets, the analysis showed no breakpoint, but a constant rate of decline of 12 percent per year. By contrast, yellow perch skin-on fillets declined sharply until 1981, and have since remained at constant levels. A meta-analysis conducted on all fish data combined yields a statistically significant, but slow rate of decline of 4.9 percent (range 2.1 to 7.5 percent decrease) per year.

Appleton to Little Rapids

For this reach, there were only sufficient data to evaluate Deposit Group IMOR, Deposit N (pre-demonstration dredging), and Deposit Group VCC. For these three groupings, surface sediments at IMOR showed an estimated annual increase of 9.9 percent, while the other two showed decreases in total PCB concentrations (Table 2-10). While Deposit N surface sediments were found to be significant, there were non-significant increases observed in the subsurface sediments. Again, confidence limits around the estimated mean for all deposits was wide. Meta-analysis for the reach showed a non-significant increase of 0.6 percent per year.

For fish in this reach, the only tissue type with sufficient numbers and time spread of data were walleye skin-on fillet. Analysis of those data showed a relatively constant rate of decline of 10 percent (range 5.6 to 17.9 percent decrease) per year (Table 2-11).

Little Rapids to De Pere

Time trends in sediments for this reach have a majority of negative slopes; but two of only three significant slopes were negative and occur in the 0- to 10-cm (0- to 4-inch) and 10- to 30-cm (0.33- to 1-foot) depth strata. One large, positive, statistically significant slope occurs at the 30- to 50-cm (1- to 1.6-foot) depth (Table 2-10, Figure 2-16).

The surface sediment (0 to 10 cm [0 to 4 inches]) in the Lower EE Deposit Group has a significantly negative slope ($p = 0.04$), implying a rate of decrease of 15 percent per year with a 95 percent confidence interval of 2 to 26 percent rate of decrease per year. In the same deposit group, the deeper 30- to 50-cm (1- to 1.6-foot) stratum shows a significantly positive slope, indicating a rate of increase of 23 percent per year and a 95 percent confidence interval of 4 to 46 percent per year. In Deposit Group FF, the 10- to 30-cm (0.33- to 1-foot) layer has a significantly negative slope with a rate of PCB concentration decrease of 20 percent per year with a 95 percent confidence interval of 1 to 35 percent. Again, while the estimates speak to significant decreasing or increasing PCB concentrations over time in these strata and deposit group combinations, the analysis showed wide confidence intervals. For surface sediments, the annual change ranged from an increase of 19.1 percent per year to a decrease of 33 percent per year.

Although only one surface sediment has a statistically significant decline, the mass-based meta-analysis found an overall statistically significant combination of declining PCB concentrations in the reach, with a slope of -0.046 per year ($p = 0.01$), implying a 10 percent per year rate of decrease (95 percent confidence interval: -17 to -2 percent). While some uncertainty may persist in the individual surface deposits, the PCB mass in the surface of this reach appears to be generally declining as of the mass estimation date, 1989 through 1990.

As noted previously, there were not sufficient fish tissue data for analysis of time trends.

De Pere to Green Bay (Zone 1)

The time trends analysis for surface sediments in this reach showed primarily negative slopes (Table 2-10). Statistically significant negative slopes were found in only three combinations of deposit group and depth. SMU Group 2649 showed a significantly negative slope ($p < 0.001$) in the surface deposit (0 to 10 cm [0 to 4 inches]), with a rate of decrease of 13 percent per year (95 percent confidence interval of 8 to 17 percent decrease per year). SMU Group 5067, 0 to 10 cm (0 to 4 inches), also has a significantly negative slope ($p = 0.01$) implying an annual rate of decrease of 21 percent (95 percent confidence interval

of 5 to 33 percent). In the same SMU group (5067), at a greater depth of 50 to 100 cm (1.6 to 3.3 feet), a significant ($p = 0.003$) and large positive slope with a rate of increase of 133 percent per year (95 percent confidence interval of 56 to 250 percent) was observed.

It is important to note that an exceptionally high value of PCB concentration in SMU Group 5067 was excluded from the analysis. Sample A3_0-4 had a concentration of 99,000 ppb, whereas all other samples in the 0- to 10-cm (0- to 4-inch) stratum in this deposit ranged from 400 to 7,800 ppb. In a statistical sense, the sample is an “outlier,” but that does not imply error in the value of 99,000.

For fish, Green Bay Zone 1 and Zone 2 PCB exposures were found to be significantly different (Table 2-11). This difference was determined using two methods: 1) cross-sectional analyses, which compared fish PCB concentrations within a single year (e.g., 1989 data only) between the zones; and 2) estimating the significant differences between time trend slopes calculated separately for the two zones. Four out of five cross-sectional analyses showed statistically significant differences, either in the relationship of lipid content and PCB concentration or in the mean PCB concentration, while controlling for lipid content. All three time trend analyses comparing the two zones showed significantly different trends in the two reaches. Thus, the time trends in the two zones were handled separately.

For Zone 1, there appears to be a significant but slow rate of decline for most fish species tested with no breakpoint identified. The exception to this pattern were carp, which showed a breakpoint in 1995, and steep significant increases in PCB concentrations of 22 percent per year. Other fish tested within the reach included gizzard shad, northern pike, walleye (fillet and whole body), white bass, and white sucker. With the exception noted for carp, all species showed a rate of decline in PCB concentrations of between 5 and 10 percent annually. Combining all data showed that there is an average rate of decline of 7 percent per year.

Green Bay Zone 2

Zone 2 shows decreasing trends with no significant breakpoints in most species tested, including carp. Significant decreases of between 4 and 15 percent annually were found in alewife, carp, and yellow perch. The exception to this was gizzard shad, which showed a significant increasing trend of 6 percent PCBs in tissues per year (Table 2-11).

2.6.4 Conclusion

The objective of the time trends analysis was to determine if PCB concentrations in the Lower Fox River were decreasing over time. For PCB concentrations in

surface sediment, the data suggest an overall decline. PCB concentrations in surface sediments in the Lower Fox River are generally decreasing over time, but apparent detectable loss is limited to the top 10 cm (4 inches) of sediment. The apparent declines observed in surface sediments is consistent with the continued observed transport of PCBs from the river to Green Bay, as discussed in Section 2.5. The rate of change in surface sediments is both reach- and deposit-specific. The change averages an annual decrease of 15 percent, but ranges from an increase of 17 percent to a decrease of 43 percent (Table 2-12). A large fraction of analyses provided little useful information for projecting future trends because of the lack of statistical significance and the wide confidence limits observed. This is especially true for sediments below the top 10 cm (4 inches); changes in the sediment PCB concentrations cannot be distinguished from zero, or no change.

PCB concentrations in fish are also generally decreasing over the analysis period. The changes in PCBs in the sediments are reflected in the significant but slow declines in fish tissue concentrations of between 5 and 7 percent annually. Exceptions to the general overall decline were noted with walleye in Little Lake Butte des Morts, carp in Green Bay Zone 1, and gizzard shad in Zone 2 where significant increases in PCB concentrations were observed. In all reaches, a breakpoint was observed in the fish tissue declines. The presence of an earlier slowing of rates of decrease in fish, along with a more recent phenomenon of changing trends in some species and sample types, suggests that fish time trends are changeable. Since PCBs in fish are derived from PCBs in sediment, the sediment rates of change may also be changeable.

It is important to note that the trends discussed are limited to the period of time for which data existed. These analyses are not suitable for projecting trends; the data do not provide the assurance of a future steady or rapid decline in PCB concentrations. Even though there are a number of negative time trends that suggest PCB declines, future projections of PCB concentrations in sediments and fish are highly uncertain. Over the period of data collection, surface sediments and fish species have, on the average, declined in PCB concentrations. Yet the presence of increases in PCB concentrations in deeper sediments, and of breakpoints and other non-linear phenomena in fish PCB time trends (on the log scale), suggest that the river, its sediment, and its species may be experiencing an arrest or reversal of such a decline. The analyzed data do not assure continued PCB decreases over time.

The time trends analysis dealt strictly with the testing of changes in PCB concentrations over time, and not with the mechanisms that could control changes in sediment and tissue loads. As discussed in Section 2.5, studies have shown that PCBs are being transported out of the Lower Fox River into Green

Bay, while PCBs in Green Bay migrate into Lake Michigan. Therefore, PCB dispersal is one factor in the observed PCB declines. In addition, some of the variability observed in the data may be accounted for by changes in river profile, burial, scour by flood or ice, and propeller wash in the lower reaches of the river. As the analysis focused solely on the existing data, these potential mechanisms could not be adequately controlled or accounted for.

The conclusions of a general decrease in PCB burdens in sediments and fish of the Lower Fox River and in Zone 1 of Green Bay are consistent with findings by other researchers in the Great Lakes. Decreases in PCB concentrations have been observed in Lake Michigan (Offenberg and Baker, 2000; DeVault *et al.*, 1996; Lamon *et al.*, 1998), Lake Ontario (DeVault *et al.*, 1996; Gobas *et al.*, 1995) and Lake Superior (Smith, 2000). The yearly rate of decline for PCBs in biota and sediment of Lake Superior has been estimated at 5 to 10 percent per year (Smith, 2000), which is generally consistent with the trends observed in the Lower Fox River (Table 2-12). However, several other researchers have also noted breakpoints, or constant levels of PCBs beginning in the mid- to late 1980s. Lake trout and smelt are reported to have been relatively constant in Lake Ontario since 1985 (Gobas *et al.*, 1995). PCB body burdens in Lake Erie walleye were shown to be declining between the periods of 1977 and 1982, but after that period remained constant through 1990 (DeVault *et al.*, 1996). Time trends analysis for salmonids in Lake Michigan showed generally decreasing tissue concentrations, but upper-bound forecast estimates for lake trout and chinook indicated that there would be a steady, or slightly increasing annual average PCB concentration. These findings are consistent with the time trends analysis for the Lower Fox River, and suggest that there may continue to be slow, gradual declines, or steady-state concentrations for many years to come.

Given the potential for disturbance and redistribution of sediments, which has been observed in the past due to scouring, there is a high degree of uncertainty in projecting future PCB concentrations in sediments and fish. Given this, coupled with similar observations for sediments and fish on other Great Lakes systems, there is too much uncertainty to apply the information to human health or ecological risk analysis. The current Fox River data shows wide confidence limits on slopes. Some important game fish such as walleye or carp, as well as forage fish (gizzard shad) show increasing PCB levels.

2.7 Section 2 Figures, Tables, and Plates

Figures, tables, and plates for Section 2 follow page 2-50 and include:

Figure 2-1 Little Lake Butte des Morts Reach

Figure 2-2 Appleton to Little Rapids Reach

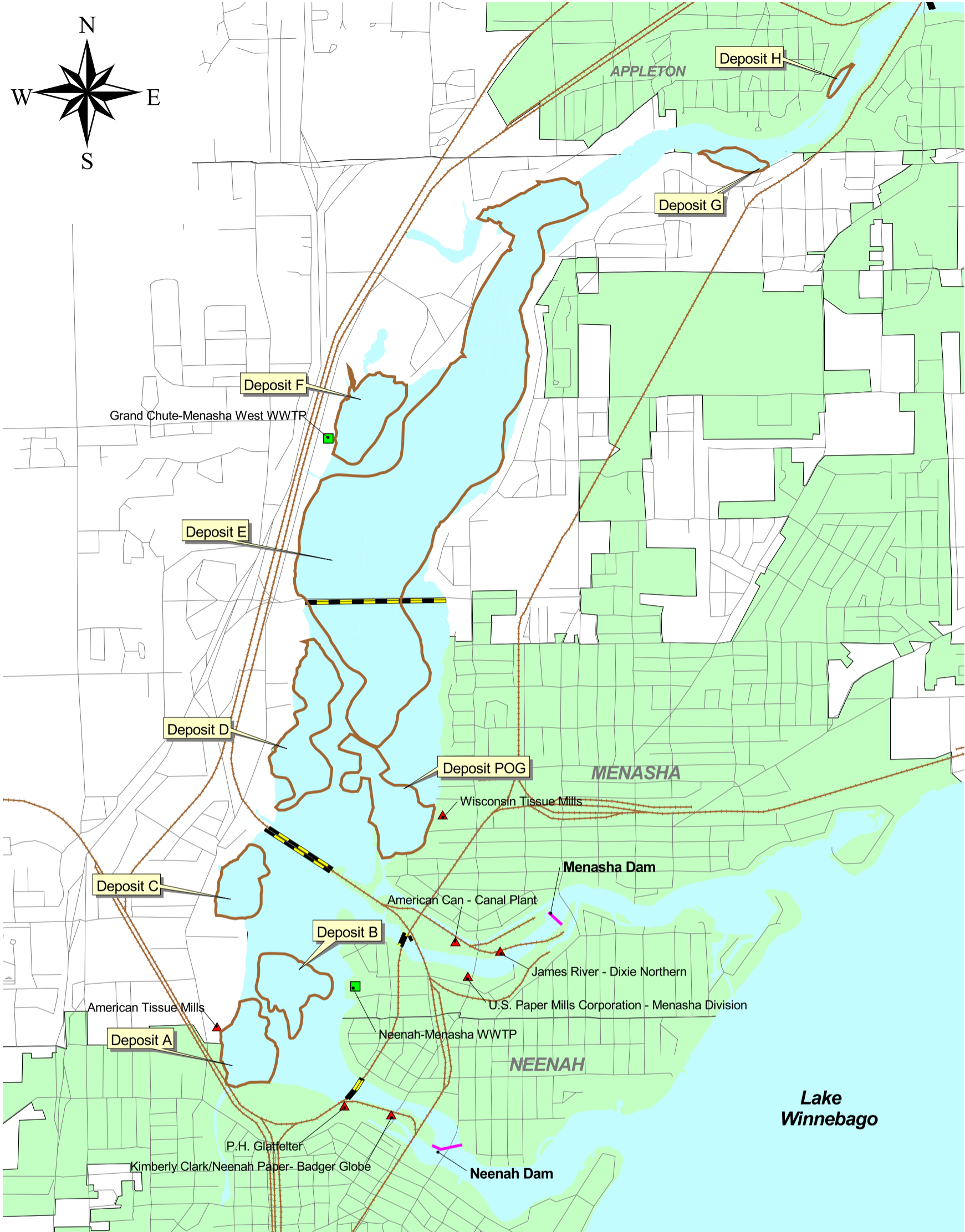
Figure 2-3	Little Rapids to De Pere Reach
Figure 2-4	De Pere to Green Bay Reach
Figure 2-5	Soft Sediment Thickness (m) and Bathymetry (ft): Little Lake Butte des Morts
Figure 2-6	Soft Sediment Thickness (m) and Bathymetry (ft): Appleton to Little Rapids
Figure 2-7	Soft Sediment Thickness (m) and Bathymetry (ft): Little Rapids to De Pere
Figure 2-8	Soft Sediment Thickness (m) and Bathymetry (ft): De Pere to Green Bay
Figure 2-9	Soft Sediment Thickness (cm) and Bathymetry (m): Green Bay
Figure 2-10	Lower Fox River Elevation Profile
Figure 2-11	Green Bay Monthly Mean Bottom Circulation—July 1989
Figure 2-12	Green Bay Monthly Mean Bottom Circulation—August 1989
Figure 2-13	Estimated Annual Sediment Transport Rates and Stream Flow Velocities
Figure 2-14	Lower Fox River and Green Bay System Estimated PCB Mass and Major PCB Flux Pathways
Figure 2-15	Time Trends of PCBs in Sediments for Depths from 0 to 10 cm and from 10 to 30 cm
Figure 2-16	Time Trends of PCBs in Sediments for Depths from 30 to 50 cm and from 50 to 100 cm
Figure 2-17	Time Trends of PCBs in Sediments for Depths over 100 cm
Table 2-1	Physical Characteristics of the Lower Fox River
Table 2-2	Physical Characteristics of Green Bay
Table 2-3	Land Use Classification for Counties Bordering Green Bay
Table 2-4	Lower Fox River Gradient and Lock/Dam Information
Table 2-5	Lower Fox River Stream Velocity Estimates
Table 2-6	Lower Fox River Discharge Results: Rapide Croche Gauging Station
Table 2-7	Lower Fox River and Green Bay Maximum PCB Sampling Depth
Table 2-8	Lower Fox River Mouth Gauging Station Results (1989–1997)
Table 2-9	Total Suspended Solid (TSS) Loads from the Lower Fox River into Green Bay
Table 2-10	Results of Sediment Time Trends Analysis on the Lower fox River
Table 2-11	Results of Fish Time Trends Analysis on the Lower Fox River
Table 2-12	Mass-weighted Combined Time Trend for 0 to 10 cm Depth by Reach
Plate 2-1	Interpolated PCB Distribution in Sediments: Little Lake Butte des Morts Reach

Plate 2-2 Interpolated PCB Distribution in Sediments: Appleton to Little Rapids Reach

Plate 2-3 Interpolated PCB Distribution in Sediments: Little Rapids to De Pere Reach

Plate 2-4 Interpolated PCB Distribution in Sediments: De Pere to Green Bay Reach

Plate 2-5 Interpolated PCB Distribution in Sediments: Green Bay



Point Source Locations

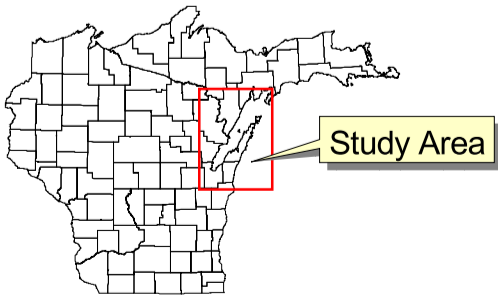
- Industrial
- Municipal
- Dam Locations
- Railroads
- Roads

Structures

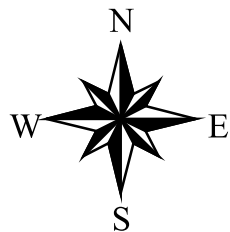
- Locks
- Bridges
- Deposits
- County Boundaries
- Water
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- City
- Township
- Village

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0.5 0 0.5 1 Miles

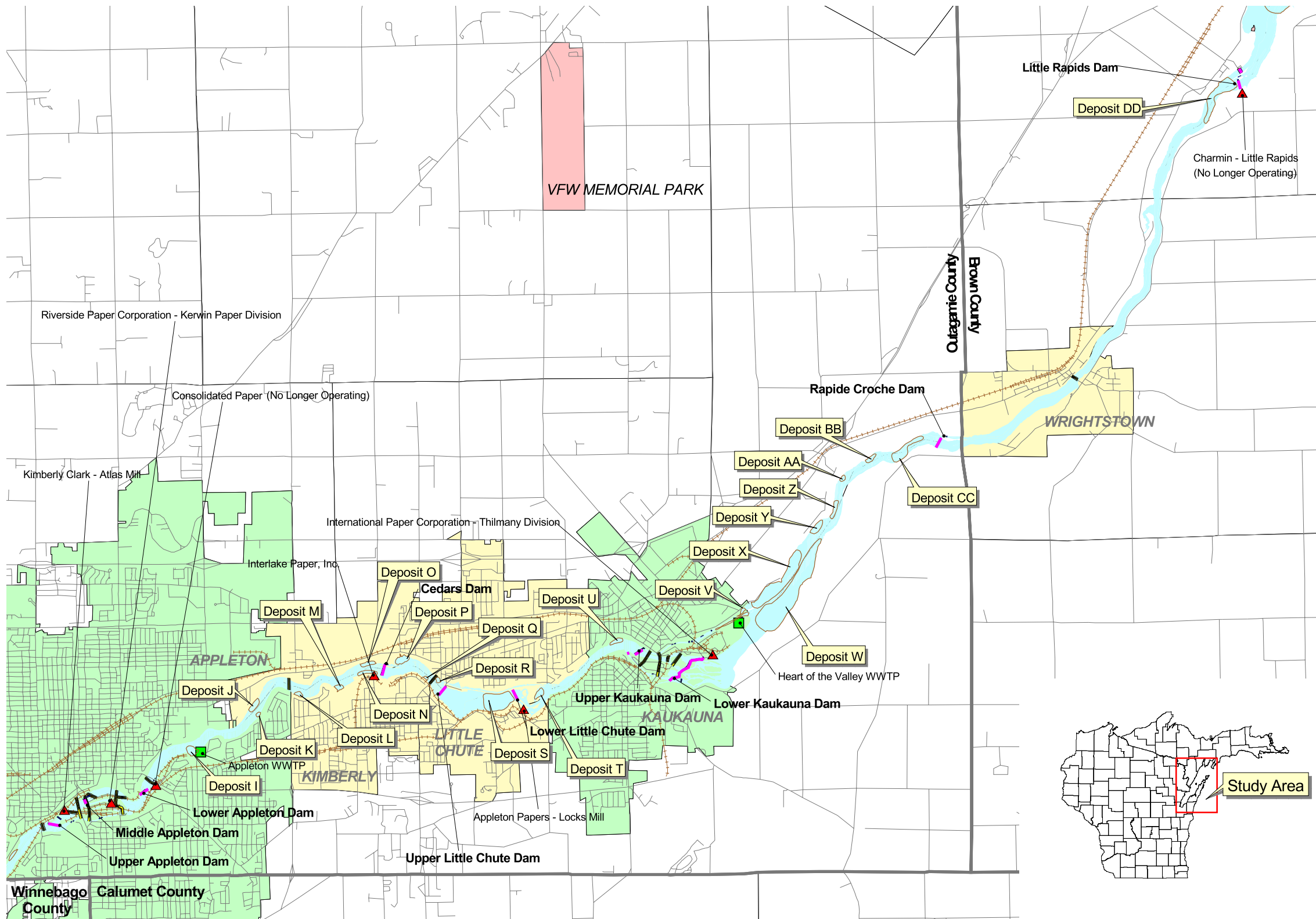


NOTES:
1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER Census data, 1995.
2. Deposit, management area, and dam location data obtained from WDNR, and are included in the Fox River database.

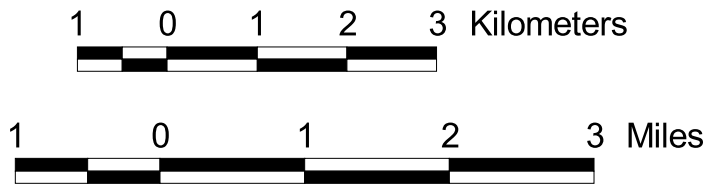


Point Source Locations

-  **Industrial**
-  **Municipal**
-  **Dam Locations**
-  **Railroads**
-  **Roads**
- Structures**
 -  **Locks**
 -  **Bridges**
-  **Deposits**
-  **County Boundaries**
-  **Water**
- Civil Divisions**
 -  **City**
 -  **Township**
 -  **Village**



NOTES:
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2. Deposit, management area, and dam location data obtained from WDNR, and are included in the Fox River database.



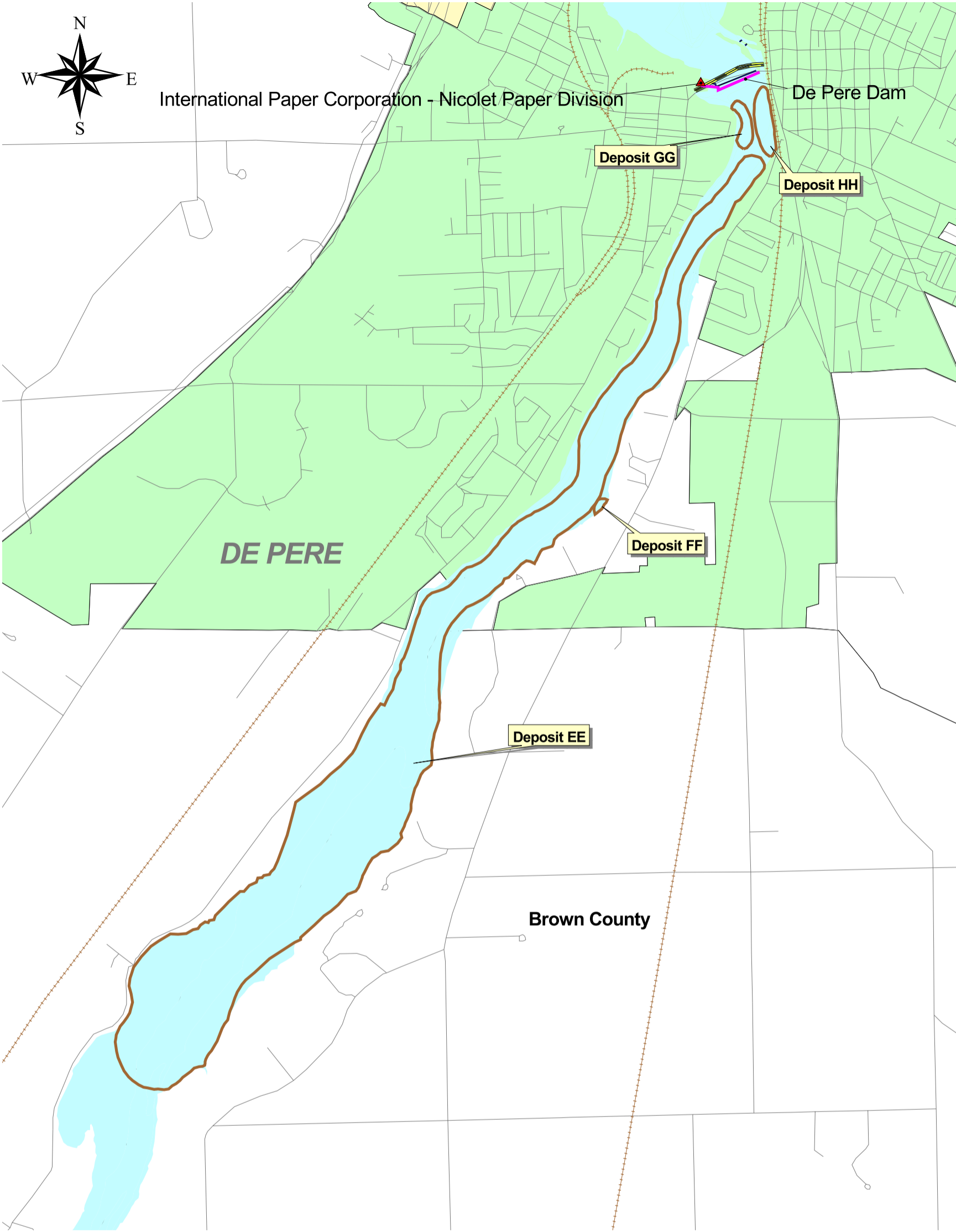
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Appleton to Little Rapids Reach

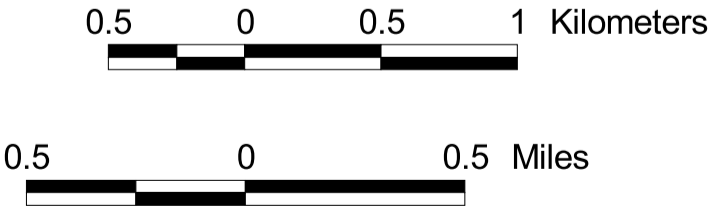
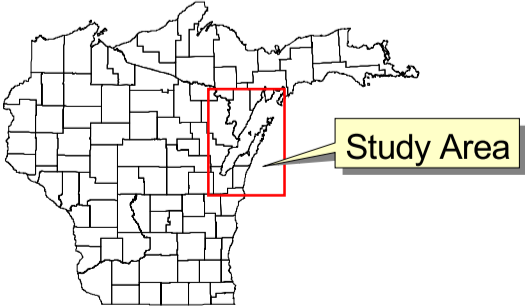
FIGURE 2-2

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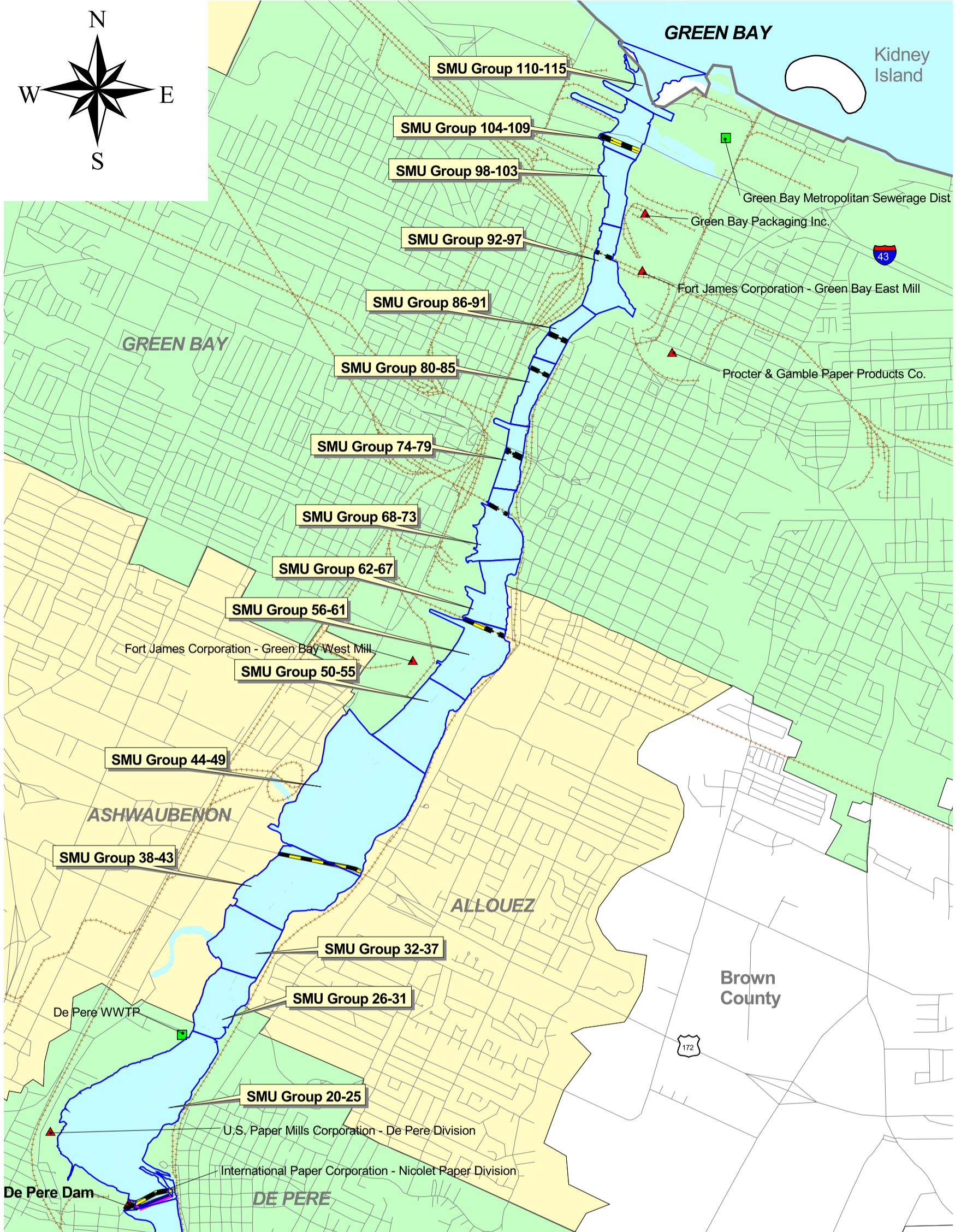


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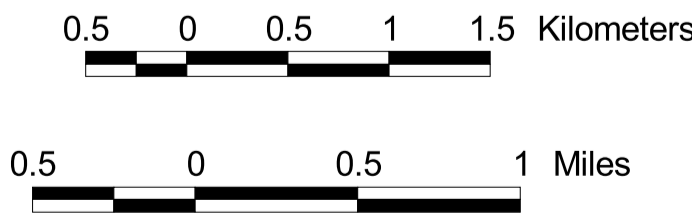
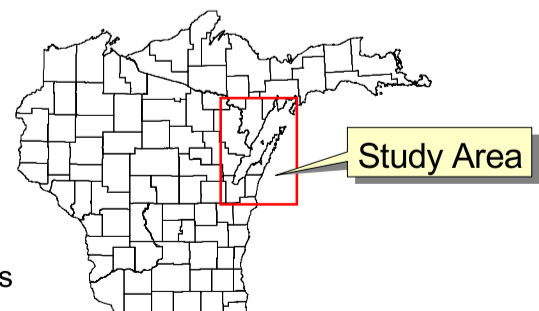
- Industrial
- Municipal
- Dam Locations
- Railroads
- Roads
- Structures
- Locks
- Bridges
- Deposits
- County Boundaries
- Water
- Civil Divisions
- City
- Township
- Village



NOTES:
1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER Census data, 1995.
2. Deposit, management area, and dam location data obtained from WDNR, and are included in the Fox River database.

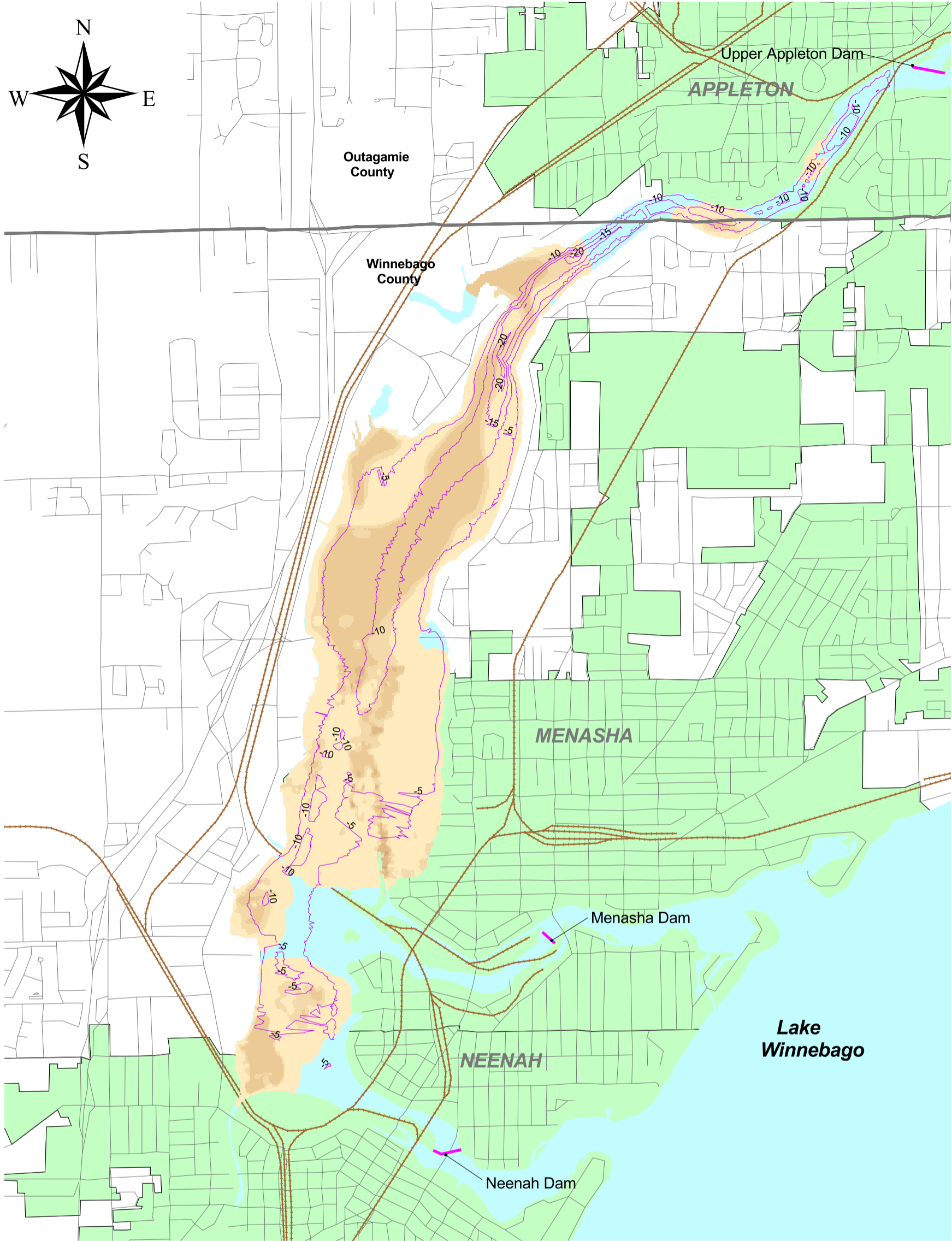


- Point Source Locations
- Industrial
 - Municipal
- Dam Locations
- Dam Locations
- Railroads
- Railroads
- Roads
- Roads
- Structures
- Locks
 - Bridges
- Sediment Management Units
- Sediment Management Units
- County Boundaries
- County Boundaries
- Water
- Water
- Civil Divisions
- City
 - Township
 - Village



NOTES:

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2. Deposit, management area, and dam location data obtained from WDNR, and are included in the Fox River database.



NOTES:

1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. Sediment thickness data obtained from WDNR, 1999, and is based on coring data.
3. Bathymetric contours (ft) obtained from IGLD, 1985.
4. Blue areas within the river or bay implies areas with no soft sediment.



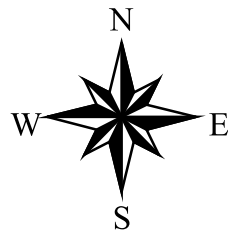
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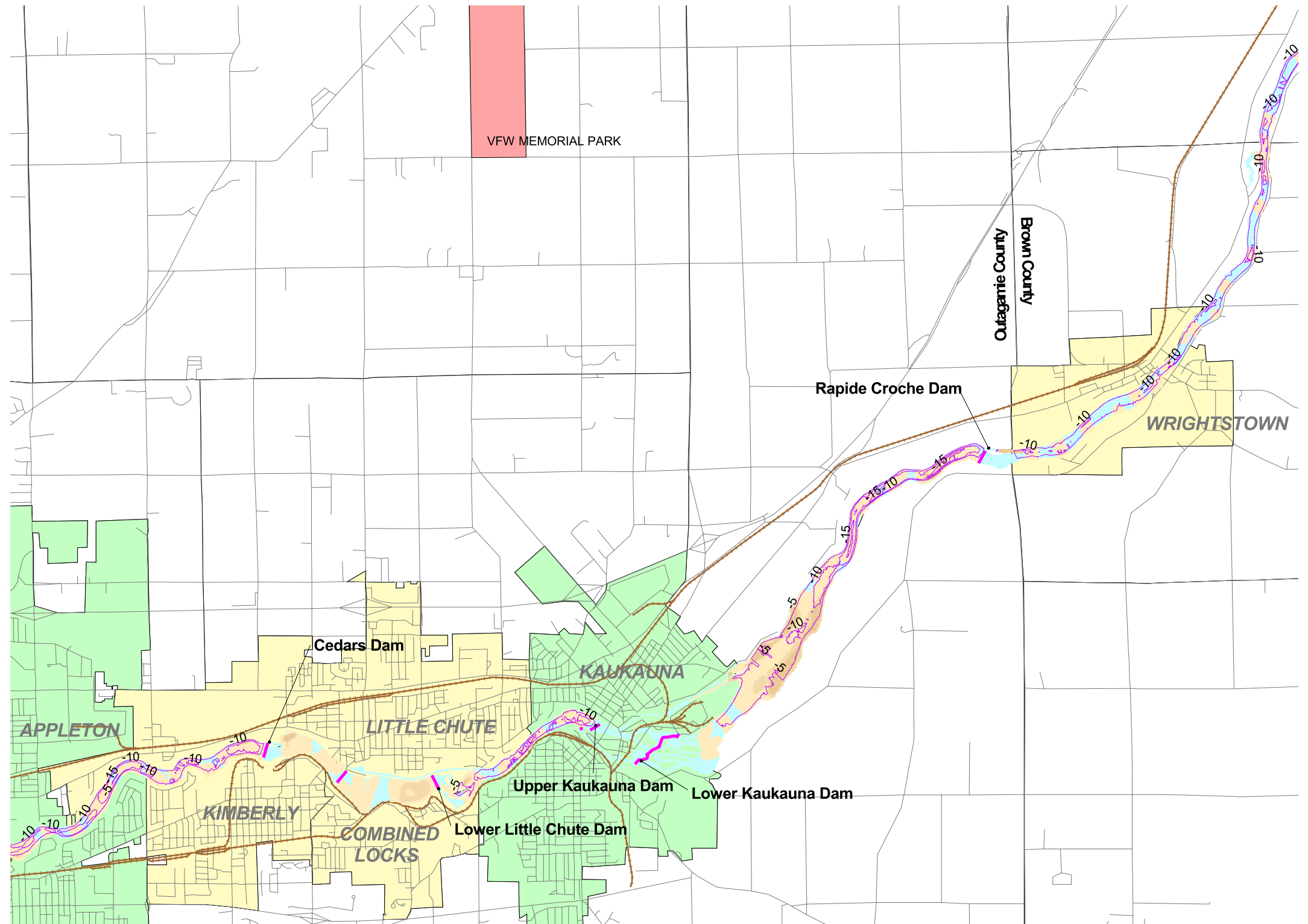
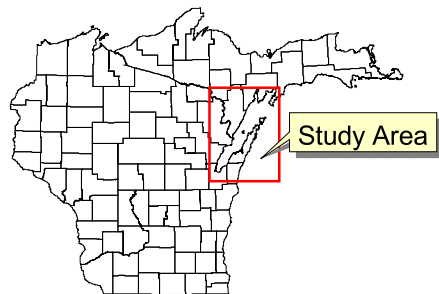
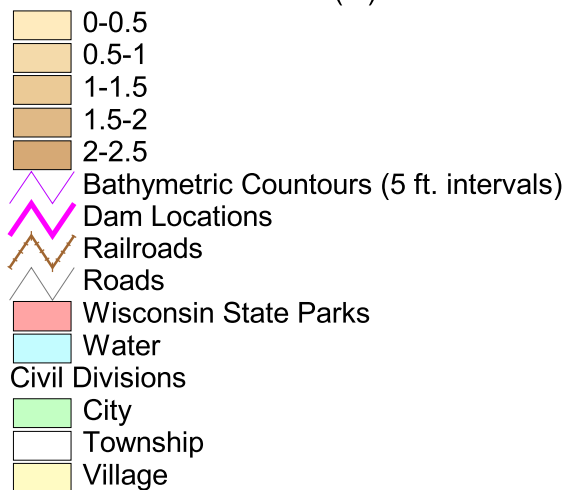
Soft Sediment Thickness (m)
and Bathymetry (ft):
Little Lake Butte des Morts

FIGURE 2-5

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Soft Sediment Thickness (m)



NOTES:
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3. Bathymetric contours (ft) obtained from IGLD, 1985.
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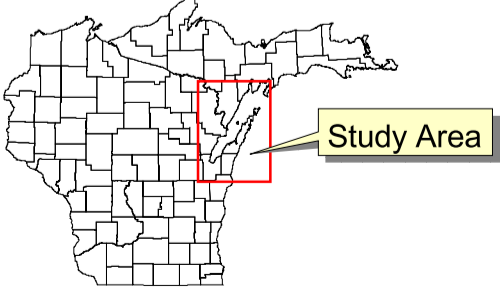
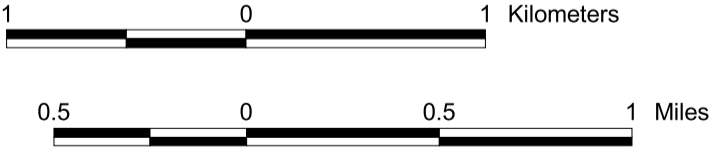
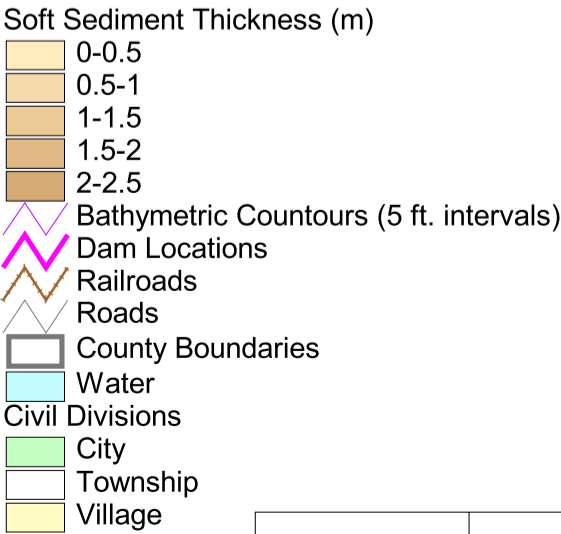
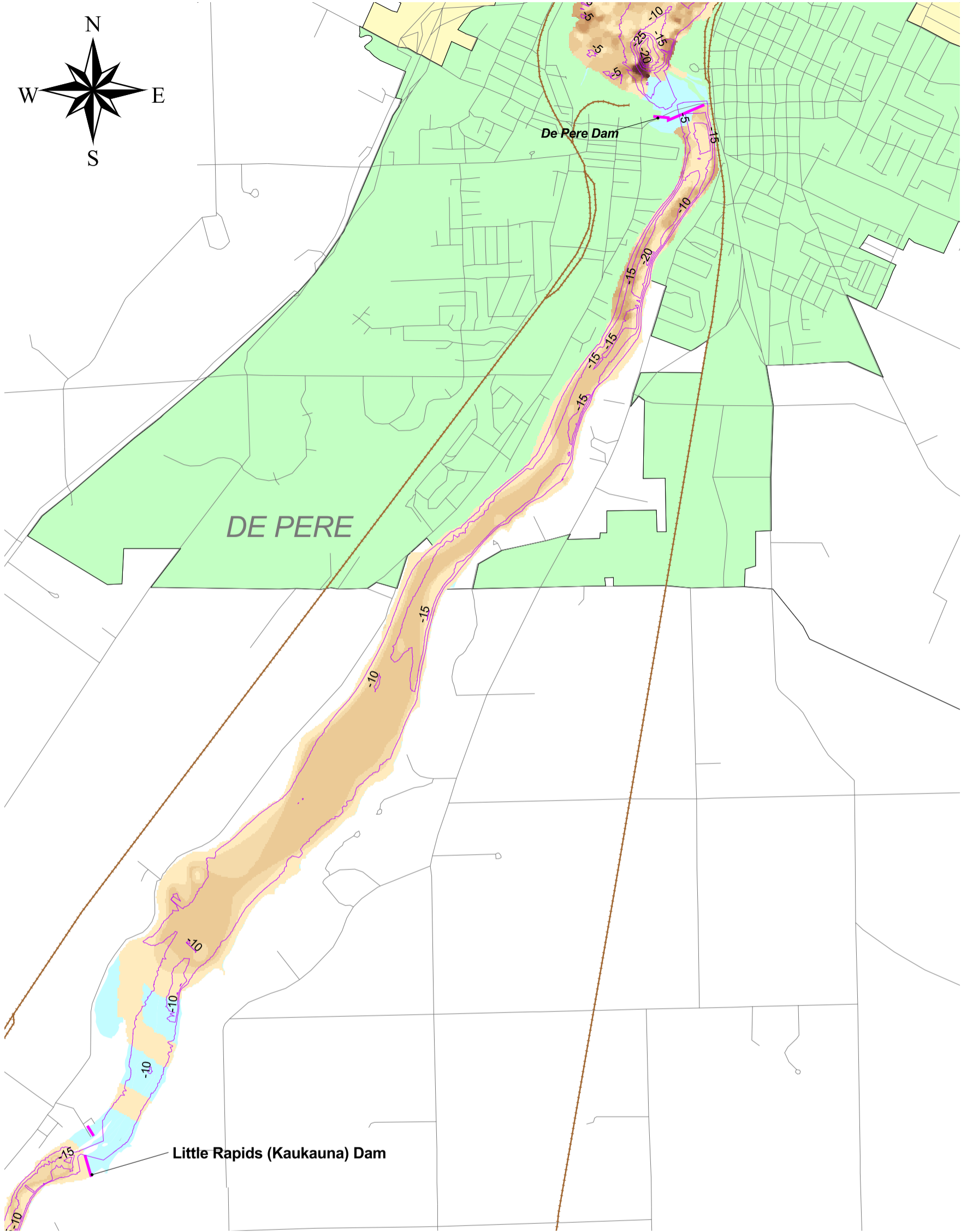
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Soft Sediment Thickness (m)
and Bathymetry (ft):
Appleton to Little Rapids

FIGURE 2-6

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- NOTES:
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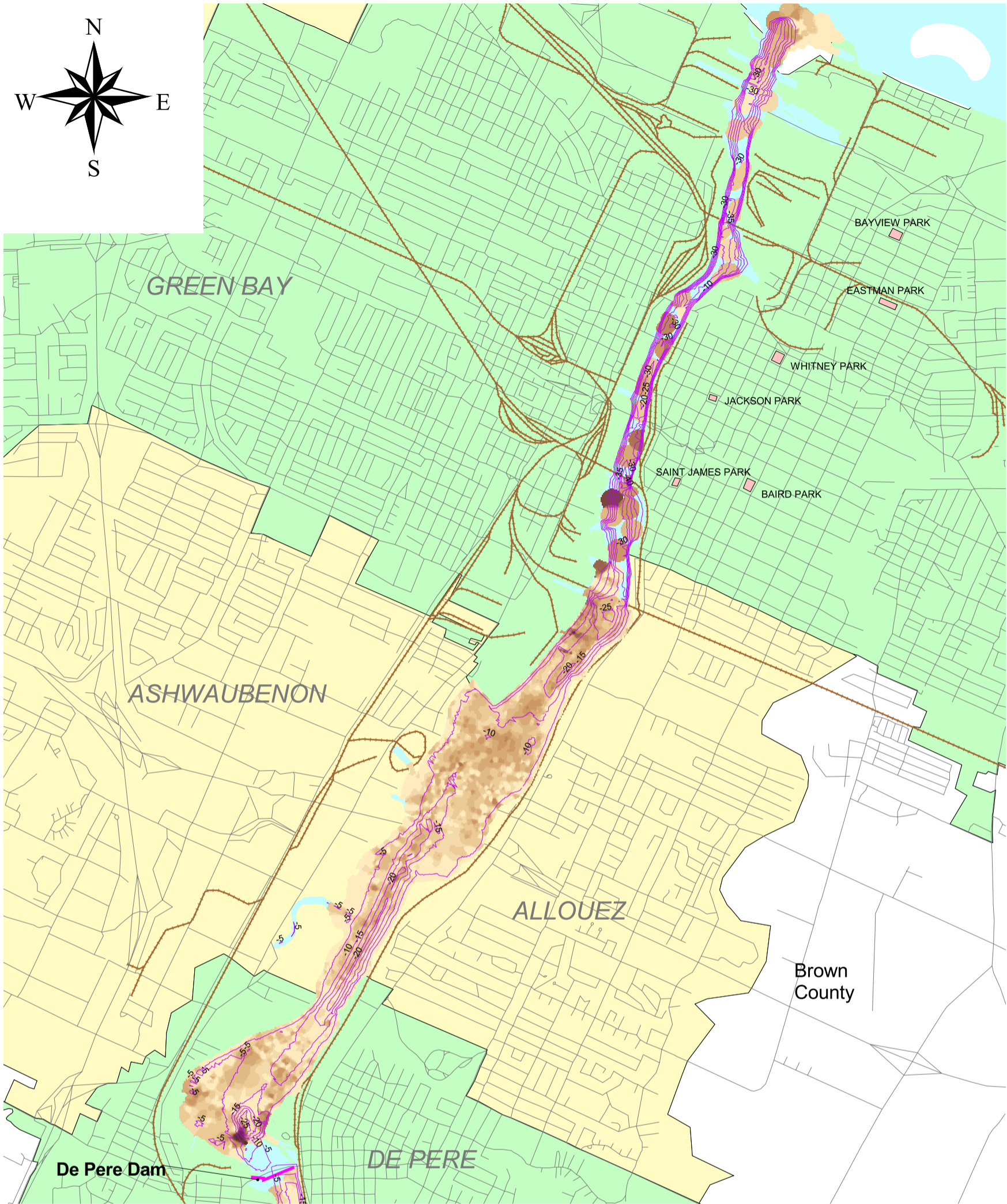
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Feasibility Study

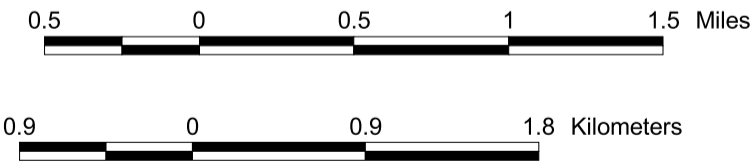
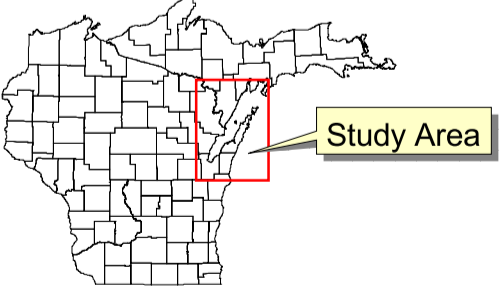
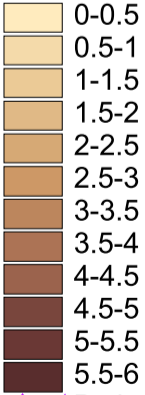
Soft Sediment Thickness (m)
and Bathymetry (ft):
Little Rapids to De Pere

FIGURE 2-7

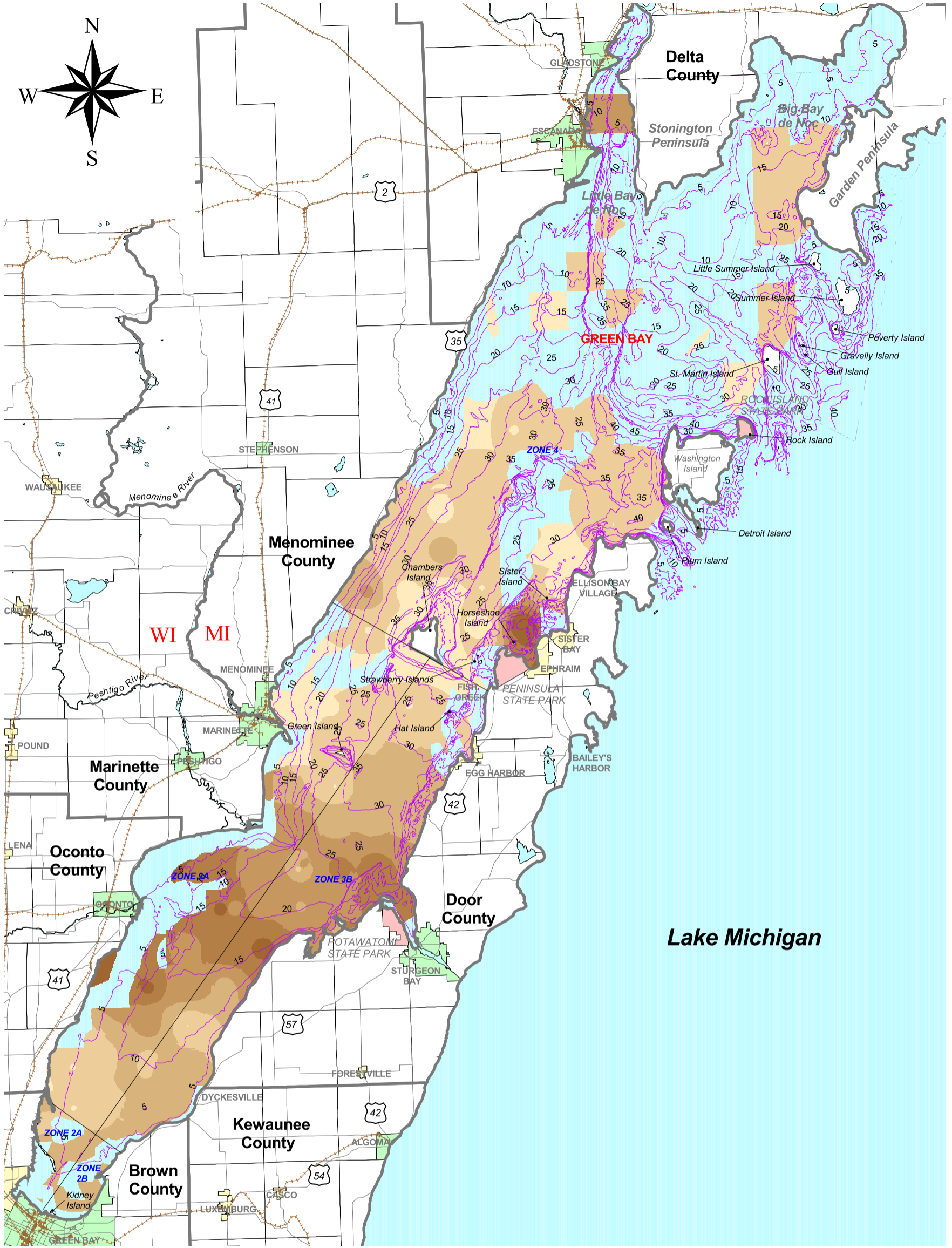
REF NO:	FS-14414-535-2-7
CREATED BY:	SCJ
PRINT DATE:	3/9/01
APPROVED:	AGF



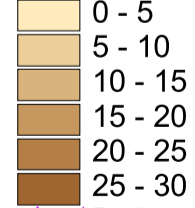
Soft Sediment Thickness (m)



NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. Sediment thickness data obtained from WDNR, 1999, and is based on coring data.
3. Bathymetric contours (ft) obtained from IGLD, 1985.
4. Blue areas within the river or bay implies areas with no soft sediment.



Soft Sediment Thickness (cm)



NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. Sediment thickness data obtained from WDNR, 1999, and is based on coring data.
3. Bathymetric contours (ft) obtained from IGLD, 1985.
4. Blue areas within the river or bay implies areas with no soft sediment.

Figure 2-10 Lower Fox River Elevation Profile

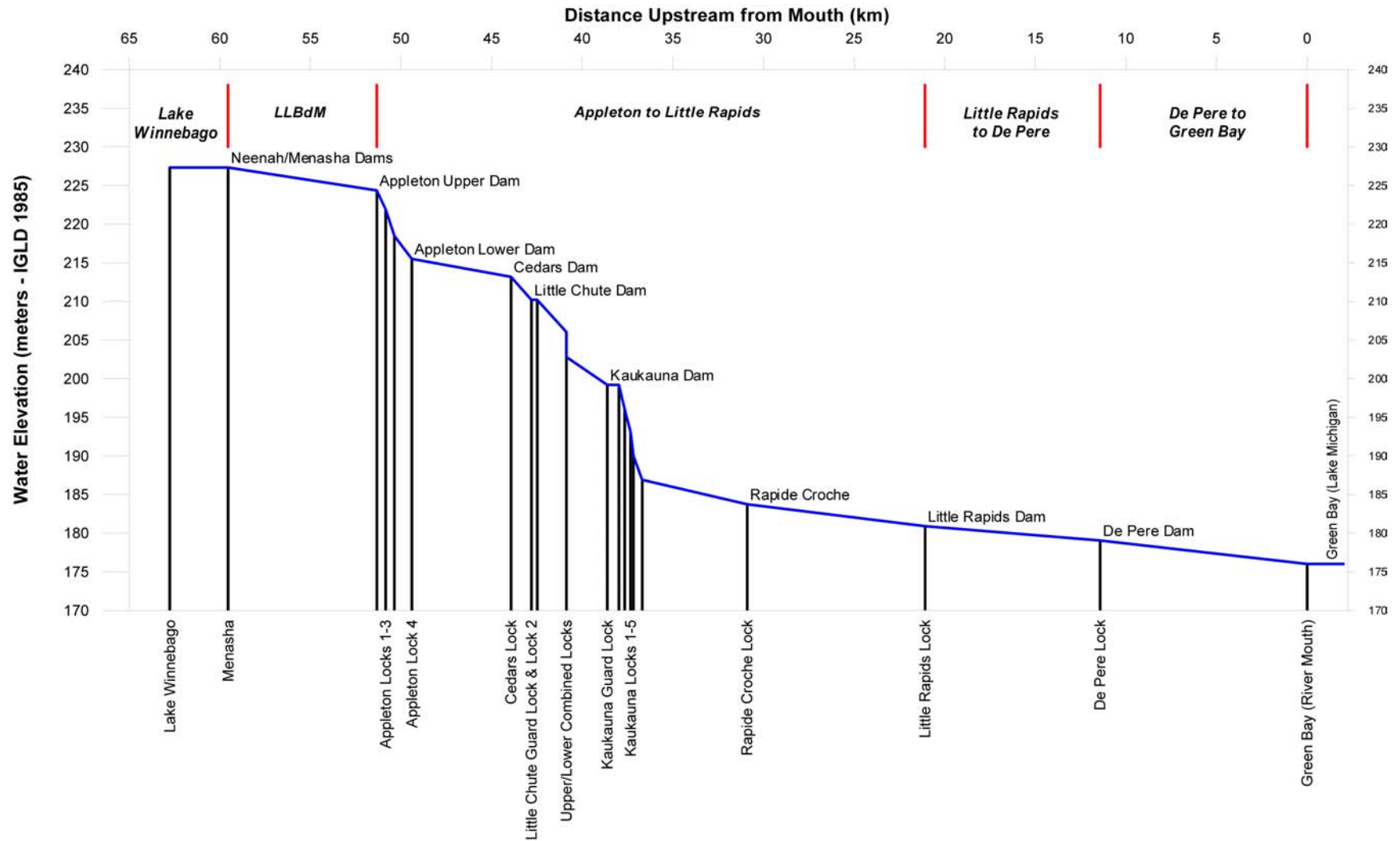


Figure 2-11 Green Bay Monthly Mean Bottom Circulation—July 1989

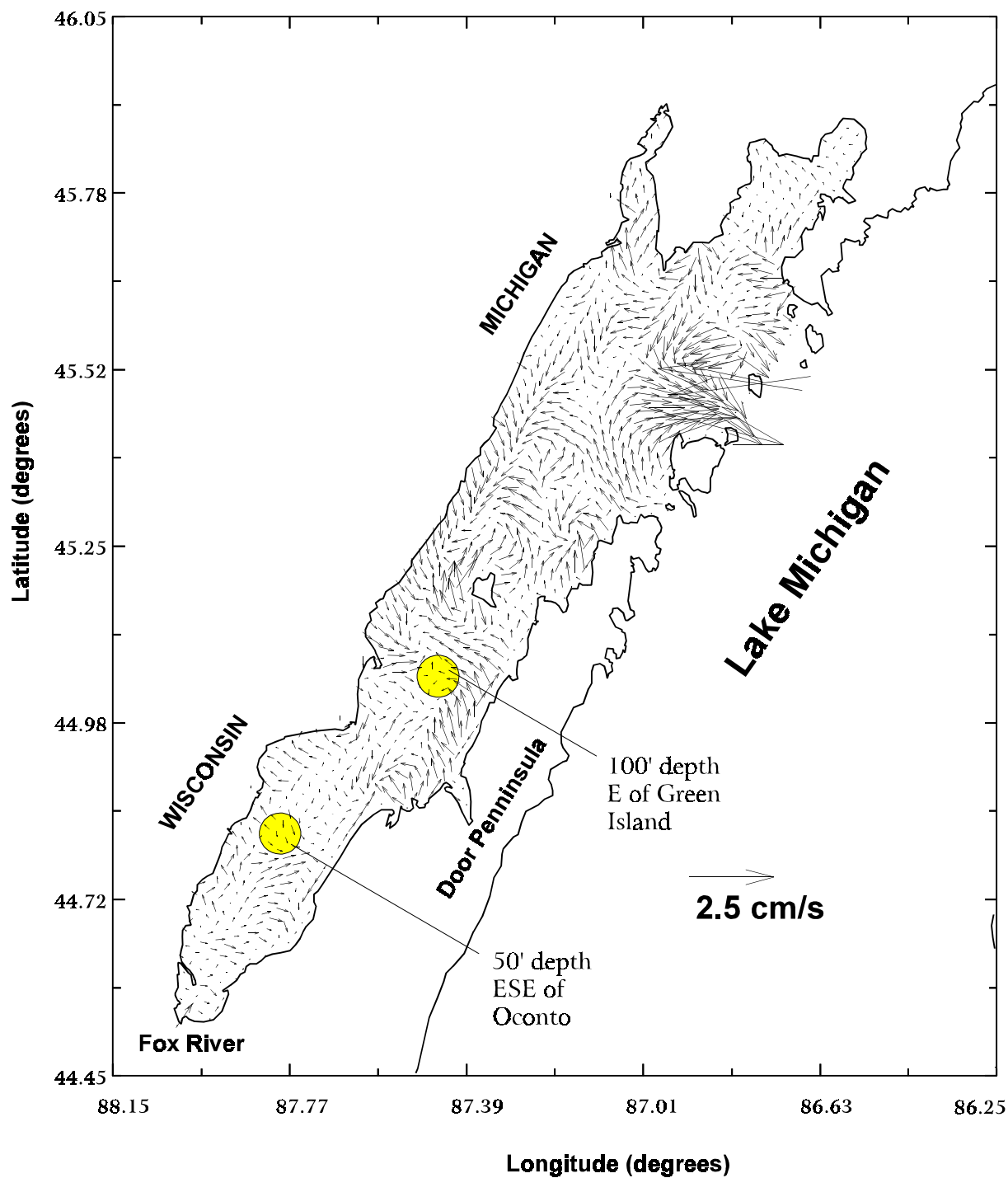


Figure 2-12 Green Bay Monthly Mean Bottom Circulation—August 1989

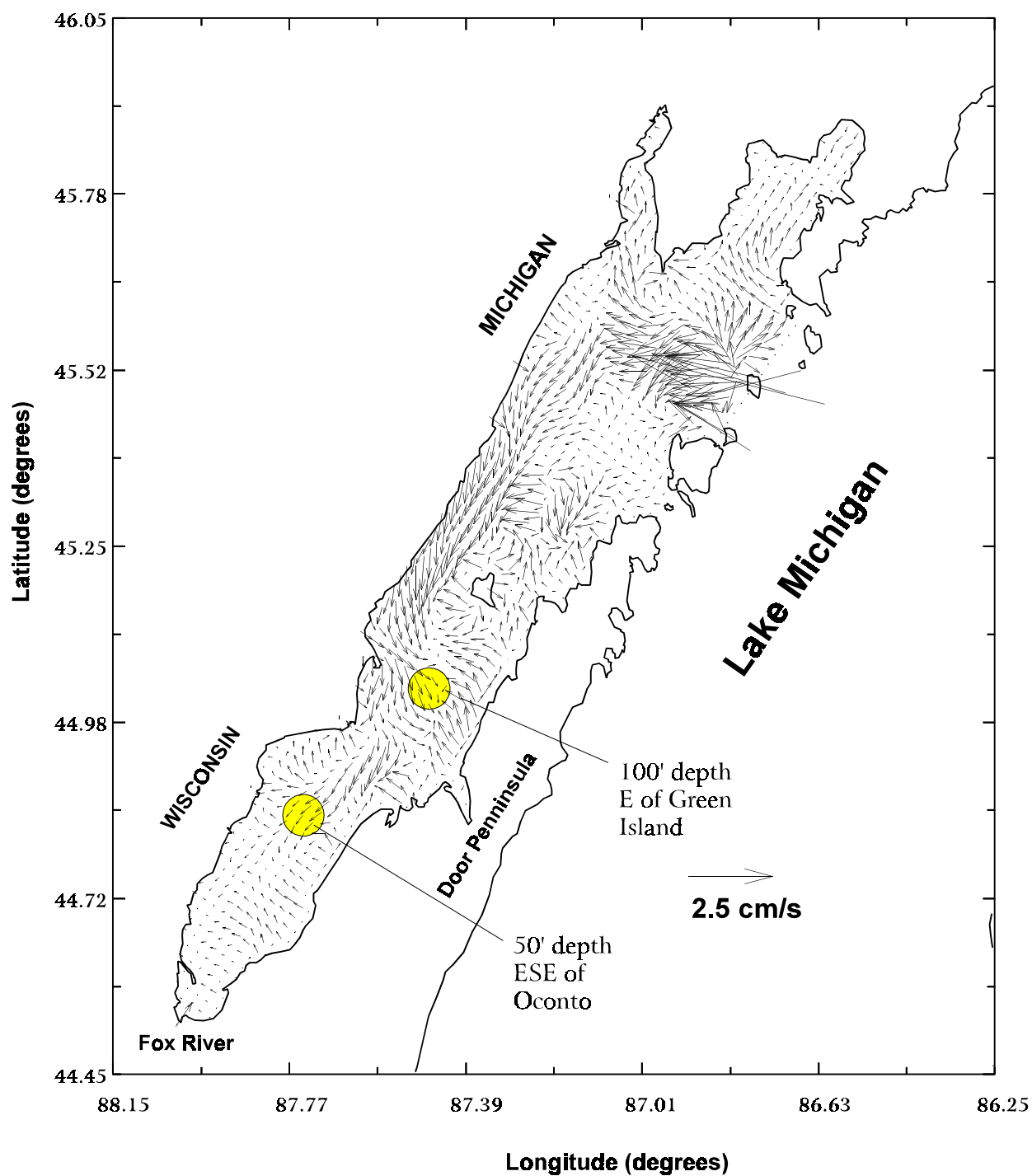
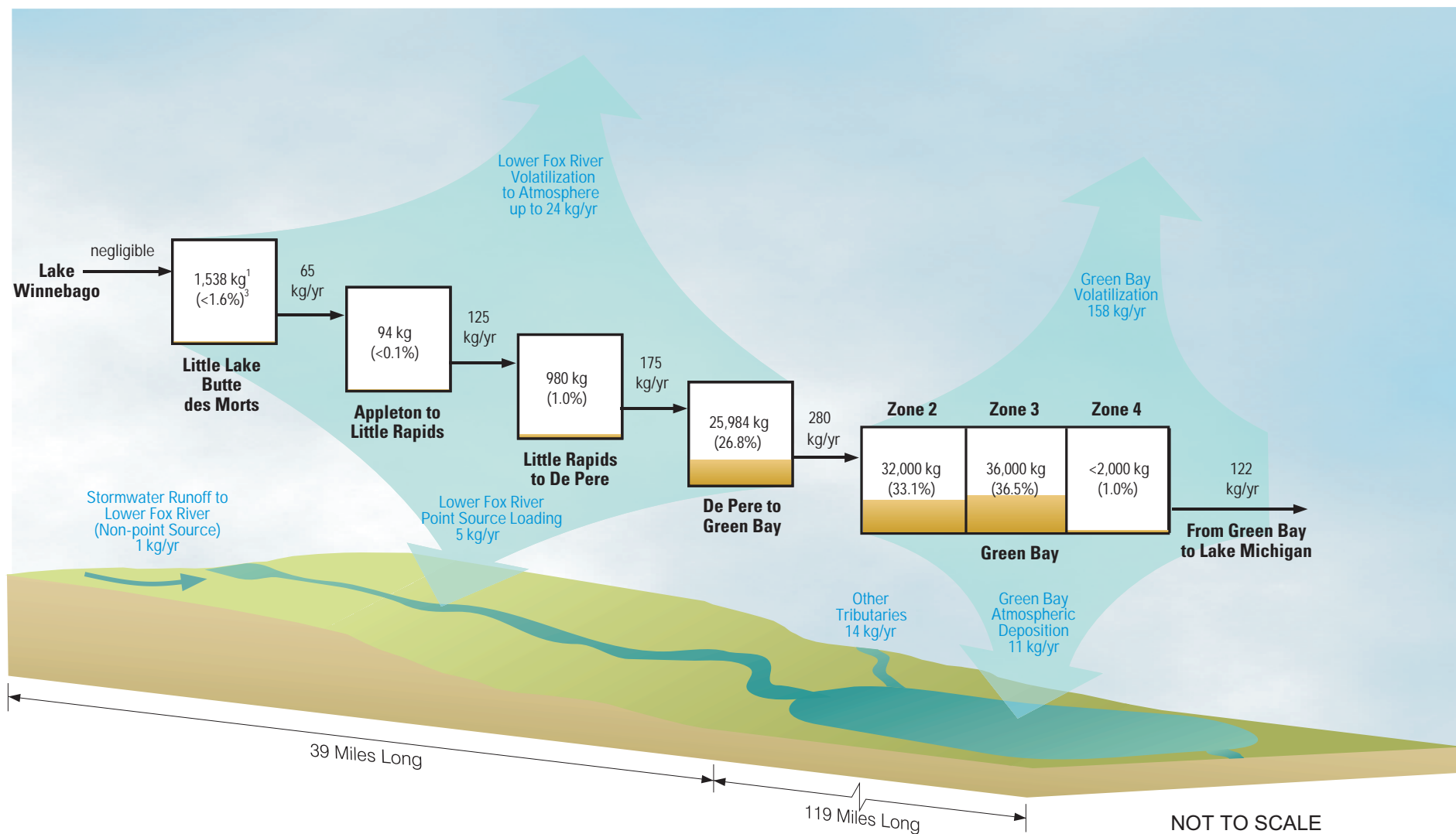


Figure 2-14 Lower Fox River and Green Bay System Estimated PCB Mass and Major PCB Flux Pathways



- Notes:
1. PCB mass in sediments with PCB concentrations of 50 µg/kg or more.
 2. Flux rates are average estimated loading rates per year.
 3. Percentages correspond to fraction of total PCB mass in project area residing in each reach or zone. PCB mass estimates obtained from Tables 5-13, 5-14 and 5-15 in the Remedial Investigation.
 4. Estimate of PCB loads from WDNR 1995 and www.epa.gov/med/images/gbmassbal.gif

Figure 2-15 Time Trends of PCBs in Sediments for Depths from 0 to 10 cm and from 10 to 30 cm

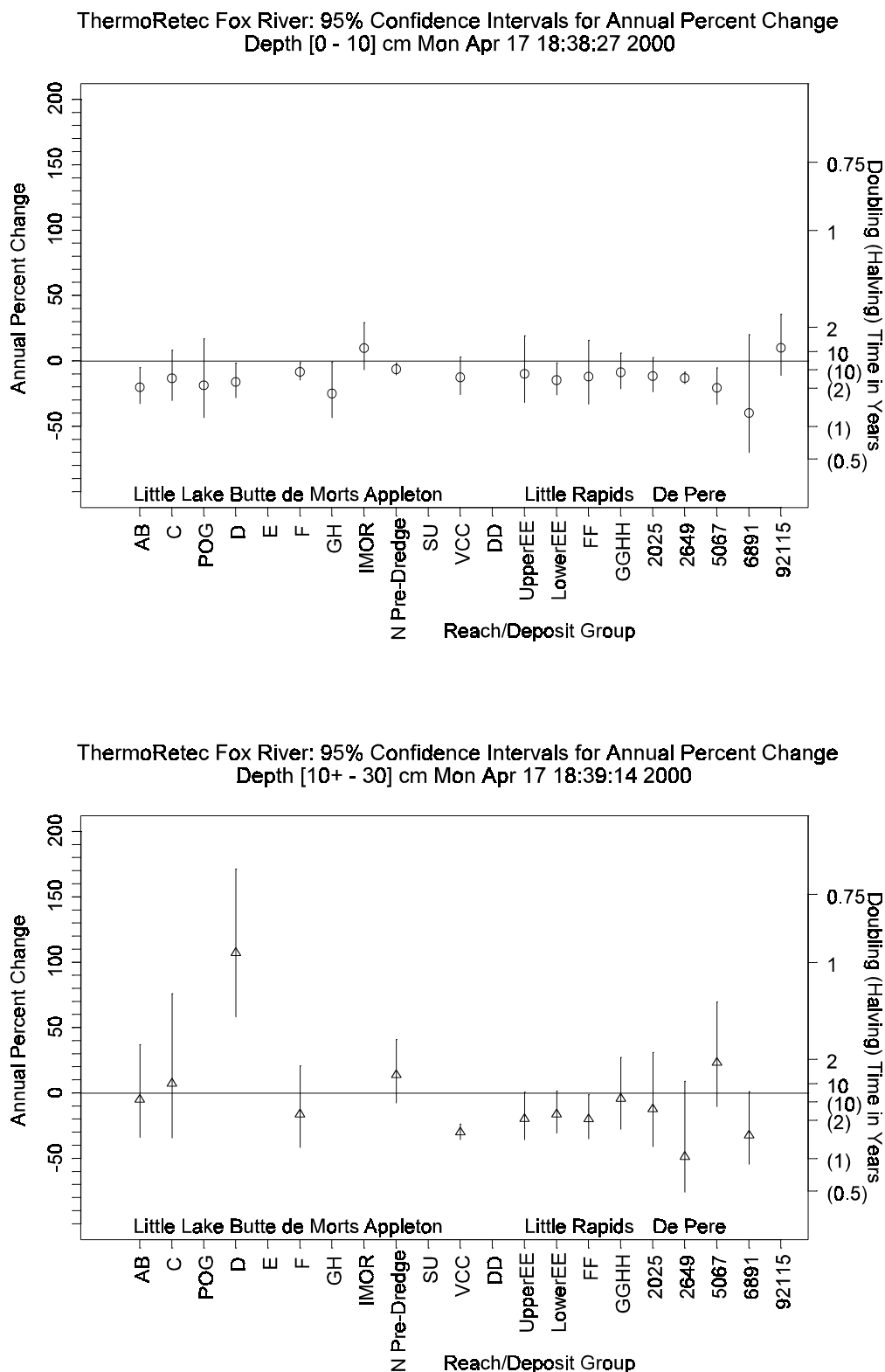


Figure 2-16 Time Trends of PCBs in Sediments for Depths from 30 to 50 cm and from 50 to 100 cm

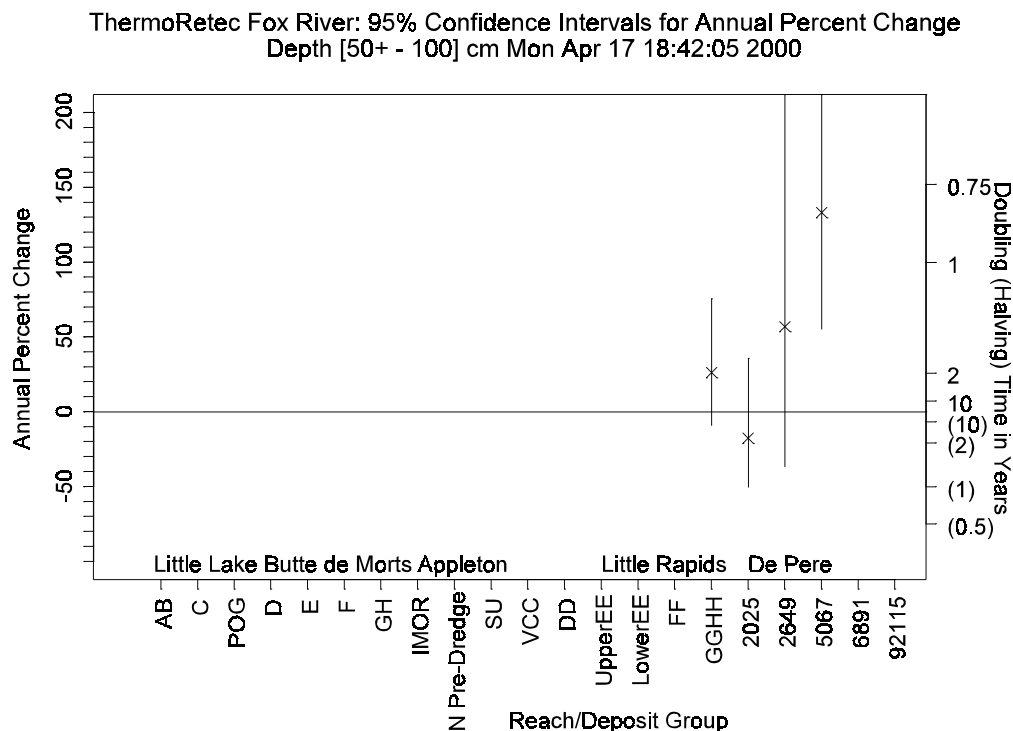
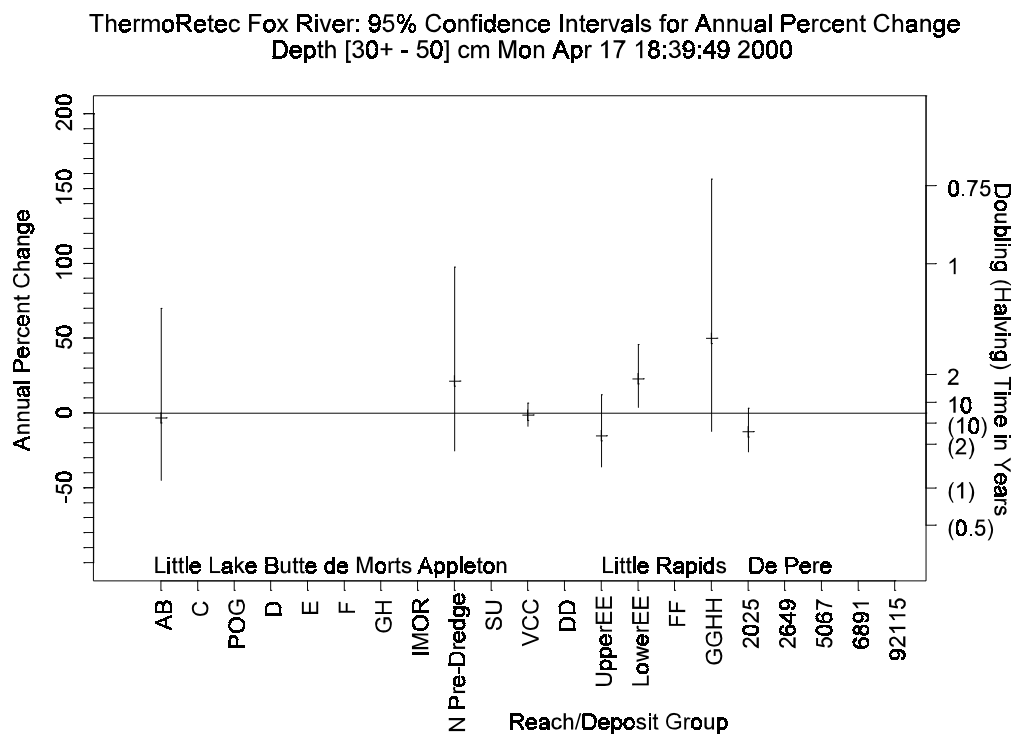
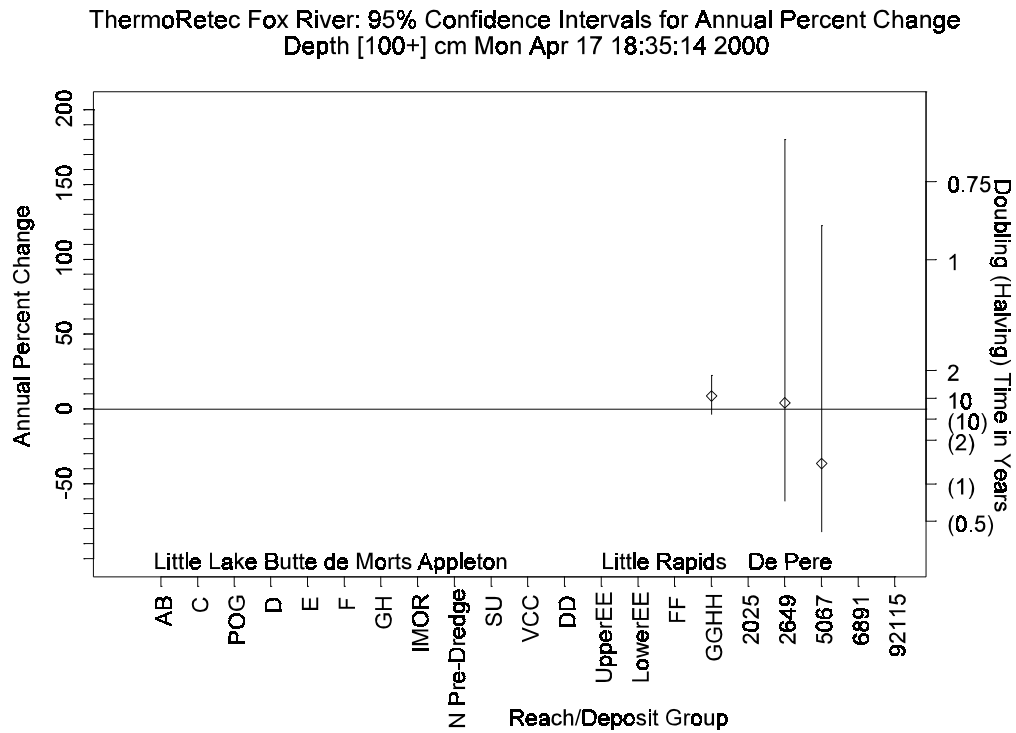


Figure 2-17 Time Trends of PCBs in Sediments for Depths over 100 cm



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Table 2-1 Physical Characteristics of the Lower Fox River

Deposit or SMU Group	Total PCB Mass ¹ (kg)	Areal Extent				Hydraulic Parameters		Grain Size (all Depths) ⁵				Percent Moisture	Average Dry Bulk Density (g/cc)	Specific Gravity
		Surface Area ¹ (hectares)	Average Thickness (m) ²	Maximum PCB Sample Depth (m) ²	Volume ¹ (m ³)	Average Flow ³ (m/s)	100-year Peak ⁴ (m/s)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)			
Little Lake Butte des Morts Reach														
Reach Total	1,847.4	313.5	0.39	1.89	1,533,205	0.16	0.82	0.6	45.7	39.0	14.7	64	0.61	2.51
A	237.4	15.3	0.71	1.80	107,730	0.19	1.07	0.0	37.5	45.2	17.3	—	0.59	NA
B	410.9	14.7	0.28	0.43	41,740	0.15	0.85	0.0	64.7	25.1	10.1	—	1.00	NA
C	38.9	12.4	0.48	0.91	59,230	0.09	0.50	0.0	26.1	53.8	20.1	—	0.42	2.59
D	82.6	25.2	0.26	1.22	66,710	0.08	0.44	0.3	43.8	44.1	11.9	—	0.62	NA
E	452.8	202.5	0.43	1.74	869,910	0.08	0.45	0.3	27.7	50.2	21.8	—	0.53	2.43
F	10.9	16.9	0.57	1.83	95,920	0.10	0.55	0.0	27.1	50.8	22.1	—	0.31	NA
G	0.7	4.1	0.20	0.30	8,380	0.35	1.10	0.0	55.7	31.0	13.3	—	0.68	NA
H	0.7	1.1	0.06	0.38	690	0.35	1.95	0.0	67.7	20.3	12.0	—	0.91	NA
POG	303.5	21.3	0.48	1.89	103,030	0.09	0.50	2.2	57.4	34.4	6.0	—	0.40	NA
IDAs ⁶	309.0	NA	NA	0.15	179,865	NA	NA	3.2	49.3	35.6	12.0	—	NA	NA
Appleton to Little Rapids Reach														
Reach Total	108.5	153.1	0.13	1.83	197,015	0.22	1.22	0.0	40.5	40.3	19.2	55	0.71	2.44
I	0.2	3.0	0.12	0.54	3,570	0.30	1.67	0.0	35.0	45.3	19.8	—	0.81	NA
J	0.1	2.5	0.06	0.42	1,630	0.30	1.67	0.0	15.0	65.7	19.3	—	0.65	NA
K	0.1	0.5	0.09	0.21	480	0.30	1.67	0.0	62.7	22.3	15.0	—	0.77	NA
L	0.1	1.1	0.05	0.30	570	0.21	1.17	0.0	45.3	34.0	20.8	—	1.02	NA
M	0.2	1.3	0.12	0.36	1,650	0.21	1.17	0.0	7.3	63.3	29.3	—	0.46	NA
N	29.6	2.3	0.22	0.89	4,880	0.21	1.17	0.5	41.1	46.9	11.6	—	—	NA
O	2.0	1.9	0.13	0.35	2,430	0.21	1.17	0.0	39.4	43.6	17.0	—	0.57	NA
P	5.3	3.1	0.41	0.94	12,800	0.21	1.17	0.0	36.0	49.6	14.4	—	0.67	NA
Q	0.2	0.4	0.05	0.55	210	0.21	1.17	0.0	49.0	39.7	11.3	—	0.49	NA
R	0.0	0.8	0.13	0.13	990	0.21	1.17	0.0	12.0	56.0	32.0	—	0.99	NA
S	0.1	16.6	0.08	0.34	12,550	0.23	1.26	0.0	46.5	36.0	17.5	—	0.54	NA
T	11.3	2.1	0.40	0.52	8,360	0.21	1.18	0.0	87.7	7.3	5.0	—	0.46	NA
U	0.2	1.7	0.03	0.26	600	0.21	1.18	0.0	51.8	35.8	12.5	—	0.76	NA
V	0.0	2.4	0.00	0.63	60	0.15	0.82	0.0	32.2	52.0	15.8	—	0.41	NA
W	6.8	56.4	0.09	1.52	53,490	0.16	0.87	0.0	50.1	32.5	17.4	—	0.66	2.34
X	2.5	25.6	0.12	1.83	30,820	0.16	0.87	0.0	33.2	52.8	14.0	—	0.52	2.54
Y	0.3	3.2	0.04	0.34	1,330	0.17	0.93	0.0	45.0	39.7	15.3	—	0.67	NA
Z	0.4	2.4	0.18	0.83	4,280	0.17	0.93	0.0	34.7	42.7	22.7	—	0.76	NA
AA	0.0	0.8	0.05	0.35	390	0.27	1.49	0.0	54.7	20.7	24.7	—	1.18	NA
BB	0.1	1.6	0.05	0.39	780	0.27	1.49	0.0	47.7	33.0	19.3	—	0.93	NA
CC	0.7	8.5	0.17	0.43	14,300	0.27	1.49	0.0	31.3	26.0	42.7	—	0.92	NA
DD	33.5	14.9	0.19	0.53	28,620	0.19	1.04	0.0	32.6	42.1	25.3	—	0.65	NA
IDAs ⁶	14.8	NA	NA	0.10	12,225	NA	NA	NA	NA	NA	NA	—	NA	NA

Table 2-1 Physical Characteristics of the Lower Fox River (Continued)

Deposit or SMU Group	Total PCB Mass ¹ (kg)	Areal Extent				Hydraulic Parameters		Grain Size (all Depths) ⁵				Percent Moisture	Average Dry Bulk Density (g/cc)	Specific Gravity	
		Surface Area ¹ (hectares)	Average Thickness (m) ²	Maximum PCB Sample Depth (m) ²	Volume ¹ (m ³)	Average Flow ³ (m/s)	100-year Peak ⁴ (m/s)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)				
Little Rapids to De Pere Reach															
Reach Total	1,245.5	266.2	0.55	2.30	1,932,690	0.12	0.68	1.6	25.1	48.1	25.2	64	0.56	2.47	
EE	828.4	258.8	0.64	2.30	1,660,390	0.12	0.68	0.5	26.8	49.7	23.0	—	0.50	2.47	
FF	0.1	0.5	0.14	0.46	700	0.12	0.68	0.0	27.2	51.6	21.1	—	0.72	NA	
GG	81.0	2.4	0.76	2.30	18,320	0.12	0.68	1.2	18.0	57.6	23.1	—	0.48	NA	
HH	70.2	4.5	0.66	2.30	29,550	0.12	0.68	2.8	21.7	57.1	18.4	—	0.53	NA	
IDAs ⁶	265.8	NA	NA	1.83	223,730	NA	NA	3.7	31.9	24.3	40.1	—	NA	NA	
De Pere to Green Bay Reach															
Reach Total	25,983.8	523.6	1.06	3.96	5,518,180	0.08	0.44	0.0	42.5	40.6	16.9	51	0.57	2.36	
20 to 25	5,557.3	113.4	0.93	2.13	1,054,580	0.07	0.39	0.0	42.3	42.5	15.2	—	0.60	2.32	
26 to 31	761.2	22.0	0.75	2.13	166,230	0.11	0.61	0.0	50.8	34.5	14.7	—	NA	NA	
32 to 37	1,172.9	26.8	0.87	2.74	233,230	0.10	0.53	0.0	31.8	49.9	18.3	—	0.34	NA	
38 to 43	1,149.5	46.5	0.87	2.74	402,360	0.08	0.43	0.0	34.5	47.4	18.1	—	0.50	NA	
44 to 49	5,211.2	107.2	1.29	3.35	1,379,690	0.07	0.37	0.0	37.8	44.6	17.6	—	0.59	2.40	
50 to 55	1,829.7	32.9	1.23	1.52	405,280	0.08	0.47	0.0	40.5	44.2	15.3	—	0.55	NA	
56 to 61	5,174.7	29.7	1.54	3.96	457,490	0.06	0.36	0.0	32.1	51.9	16.0	—	0.65	NA	
62 to 67	861.3	18.2	1.05	2.13	190,570	0.07	0.37	0.0	29.8	51.7	18.6	—	NA	NA	
68 to 73	1,858.2	21.6	1.56	2.74	337,250	0.06	0.37	0.5	34.8	41.6	23.1	—	0.39	NA	
74 to 79	430.2	11.8	1.20	1.52	141,950	0.07	0.38	0.0	34.8	42.2	23.0	—	0.71	NA	
80 to 85	385.3	10.6	1.55	2.13	164,650	0.09	0.49	0.0	45.4	36.8	17.8	—	NA	NA	
86 to 91	253.1	11.3	0.92	2.13	103,400	0.08	0.45	0.0	45.5	37.6	17.0	—	0.78	NA	
92 to 97	254.8	19.8	0.60	0.91	118,500	NA	NA	0.0	60.3	27.9	11.8	—	0.62	NA	
98 to 103	94.3	14.0	0.59	0.91	82,200	NA	NA	0.0	73.2	17.8	9.0	—	NA	NA	
104 to 109	151.1	17.0	0.44	0.30	74,550	NA	NA	0.0	41.7	40.5	17.8	—	0.63	NA	
110 to 115	839.0	20.8	1.52	1.52	206,250	NA	NA	0.0	44.2	38.9	16.9	—	0.50	NA	
Entire River Values ⁷	29,185	1,256	0.53	3.96	9,181,090	0.15	0.79	0.6	38.4	42.0	19.0	59	0.61	2.45	

Notes:¹ Volume, mass and surface area listed in the table corresponds to the 50 ppb action level.² The average thickness is based on surface area and volume of sediment. The maximum thickness is represented by the deepest sampling depth interval.³ The average flow for the river is 122 m³/s.⁴ The 100-year peak stream flow is 680 m³/s.⁵ Grain size results are averaged for all samples collected, regardless of depth. Gravel content is difference of 100 and sum of sand/silt/clay content.⁶ IDAs are inter-deposit areas in each reach.⁷ Physical characteristics generated from data in the Fox River Database (except flow) and may vary from PCB mass and volume estimates generated in later sections for remediation.⁸ NA - Parameter value or average value is not available.⁹ "—" - Percent moisture value averaged for reach.

Table 2-2 Physical Characteristics of Green Bay

Deposit or Zone	Total PCB Mass ¹ (kg)	Areal Extent				Hydraulic Parameters		Grain Size (all Depths)				Percent Moisture	Average Bulk Density (g/cc)	Specific Gravity
		Surface Area ¹ (hectares)	Average Thickness (m) ²	Maximum PCB Sample Depth (m) ²	Volume ¹ (m ³)	Average Flow ³ (m/s)	100-year Peak ⁴ (m/s)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)			
Bay Totals	67,556	421,288	0.25	0.91	465,396,800	0.05	unknown	0.4	82.7	11.4	5.6	NA	NA	NA
2A	14,118	5,931	0.34	0.91	20,033,600	0.05	unknown	0.1	73.3	18.0	8.6	NA	NA	NA
2B	17,273	5,150	0.38	0.91	19,458,000	0.05	unknown	0.1	73.3	18.0	8.6	NA	NA	NA
3A	18,537	85,891	0.21	0.30	181,301,800	0.05	unknown	0.0	98.4	0.8	0.9	NA	NA	NA
3B	16,703	69,339	0.31	0.62	215,681,400	0.05	unknown	0.1	62.7	24.9	12.4	NA	NA	NA
4	925	254,977	0.01	0.30	28,922,000	0.05	unknown	1.4	96.3	1.9	0.5	NA	NA	NA

Note:

¹ Volume, mass and surface area listed in the table corresponds to the 50 ppb action level.

² The average thickness is based on surface area and volume of sediment. The maximum thickness is represented by the deepest sampling depth interval

³ The average flow for the bay is based on HydroQual Modeling Efforts (Blumberg *et al.*, 2000).

⁴ The 100-year peak stream flow is unknown within Green Bay.

⁵ NA - Parameter value or average value is not available.

Table 2-3 Land Use Classification for Counties Bordering Green Bay

Land Use Class	Wisconsin Counties										Michigan Counties				Total Land Usage ⁶	
	Brown ¹		Door ²		Kewaunee ³		Oconto ⁴		Marinette ⁵		Menominee		Delta			
	Percent	Hectares	Percent	Hectares	Percent	Hectares	Percent	Hectares	Percent	Hectares	Percent	Hectares	Percent	Hectares	Percent	Hectares
Residential	7.8%	10,687	4.0%	5,092	1.9%	172	3.1%	1,904	0.4%	1,483	1.0%	2,726	1.2%	3,661	1.9%	24,984
Ind./Com.	9.3%	12,742	0.9%	1,146	3.3%	297	0.7%	426			0.7%	1,908	0.9%	2,746	1.5%	19,882
Agriculture	58.6%	80,275	49.3%	62,758	69.1%	6,187	37.3%	23,307	12.2%	45,227	14.4%	39,251	8.7%	26,543	22.1%	283,547
Forested			34.1%	43,409	21.7%	1,947	51.6%	32,210	53.1%	196,849	71.9%	195,954	76.2%	232,419	55.0%	705,816
Open	6.7%	9,180	3.3%	4,201	0.4%	38	5.5%	3,454	8.6%	31,881	4.4%	11,993	3.9%	11,899	5.2%	66,477
Vacant			0.1%	127			0.0%	22	0.6%	2,187	0.01%	27	0.01%	31	0.4%	5,443
Public	7.8%	10,687	6.5%	8,274	0.1%	7	0.6%	358	0.01%	37	0.1%	273	0.01%	31	1.5%	19,666
Wetlands	9.8%	13,427	0.6%	764	3.3%	295	0.1%	40	23.0%	85,264	6.8%	18,535	8.3%	25,323	11.2%	143,648
Water	0.01%	14	1.2%	1,528	0.1%	7	1.1%	686	2.1%	7,785	0.7%	1,908	0.8%	2,441	1.1%	14,368
Total:	100.0%	137,011	100.0%	127,298	100.0%	8,951	100.0%	62,408	100.00%	370,714	100.0%	272,574	100.00%	305,091	100.0%	1,283,831

Notes:

Ind./Com. is Industrial/Commercial. This category also includes lands designated for transportation/utility use.

Open land is non-forested land not currently under cultivation.

¹ For Brown County, there was no distinction between forested, open, and vacant land use.

² For Door County, wetlands, beaches, marshes, grasslands, and meadows are combined and equal about 0.6% of land designated as wetlands.

³ For Kewaunee County, only land use in the Town of Red River was available. This is the area which borders Green Bay and in which Dyckesville is located. Also, open and vacant land are not distinguished.

⁴ Land use information only available for the eastern one-quarter of Oconto County. Total area of Oconto County is 263,442 hectares (650,976 acres).

⁵ There was no distinction of urban land use between residential and industrial/commercial or Marinette County.

⁶ Combined classifications were divided equally when calculating total land usage values.

Table 2-4 Lower Fox River Gradient and Lock/Dam Information

Lock	Lock Water Elevation (meters IGLD*)	Lock Water Elevation (feet IGLD*)	Dam	Dam Water Elevation (meters IGLD*)	Dam Water Elevation (feet IGLD*)	Miles Upstream	Gradient**
Lake Winnebago	227.11	745.10		227.11	745.10	39.0	—
Menasha	227.11	745.10	Menasha Dam	227.09	745.03	37.0	6.6E-06
Appleton Lock 1	224.15	735.40	Appleton Upper Dam	224.15	735.40	31.9	3.6E-04
Appleton Lock 2	221.19	725.70				31.6	
Appleton Lock 3	218.27	716.10				31.3	
Appleton Lock 4	215.28	706.30	Appleton Lower Dam	215.27	706.25	30.7	4.6E-03
Cedars Lock	212.96	698.70	Cedars Dam	212.95	698.66	27.3	4.2E-04
Little Chute Guard Lock	209.98	688.90	Little Chute Dam	209.97	688.88	26.6	2.6E-03
Little Chute Lock 2	209.98	688.90				26.4	
Upper Combined Lock	205.83	675.30				25.4	
Lower Combined Lock	202.60	664.70				25.4	
Kaukauna Guard Lock	198.97	652.80	Kaukauna Dam	198.96	652.76	24.0	2.6E-03
Kaukauna Lock 1	198.97	652.80				23.6	
Kaukauna Lock 2	195.83	642.50				23.4	
Kaukauna Lock 3	192.91	632.90				23.2	
Kaukauna Lock 4	189.80	622.70				23.1	
Kaukauna Lock 5	186.69	612.50				22.8	
Rapide Croche Lock	183.52	602.10	Rapide Croche	183.52	602.10	19.2	2.0E-03
Little Kaukauna (Little Rapids) Lock	180.69	592.80	Little Kaukauna (Little Rapids) Dam	180.69	592.80	13.1	2.9E-04
De Pere Lock	178.83	586.70	De Pere Dam	178.81	586.66	7.1	1.9E-04
Green Bay (River Mouth)	175.81	576.80	Green Bay (River Mouth)	175.81	576.80	0.0	2.6E-04
Entire River:		—	—		—	—	8.2E-04

Notes:

Information obtained from the USACE and from the NOAA Recreational Atlas 14916 (1992).

* IGLD - International Great Lakes Datum, 1955.

** Gradient values from upstream dam to this dam.

Table 2-5 Lower Fox River Stream Velocity Estimates

Model Segments	Deposits Within Lower # Segment	Cross-sectional Area (ft²)	Cross-sectional Area (m²)	Flow Velocity (m/s)									
				Average Flow (4,300 cfs)	@ Average Flow (122 m³/s)	10-year Peak (19,200 cfs)	@ 10-year Peak (544 m³/s)	10-year Low (950 cfs)	@ 10-year Low (27 m³/s)	100-year Peak (24,000 cfs)	@ 100-year Peak (680 m³/s)	100-year Low (140 cfs)	@ 100-year Low (4 m³/s)
Little Lake Butte des Morts Reach													
2/3	A	6,832.6	634.8	0.63	0.192	2.81	0.857	0.14	0.042	3.51	1.071	0.02	0.006
3/4	B	8,640.3	802.7	0.50	0.152	2.22	0.677	0.11	0.034	2.78	0.847	0.02	0.005
4/6	C, POG	14,762.7	1,371.5	0.29	0.089	1.30	0.396	0.06	0.020	1.63	0.496	0.01	0.003
6/7	D, E	16,678.0	1,549.4	0.26	0.079	1.15	0.351	0.06	0.017	1.44	0.439	0.01	0.003
7/8	D, E	16,097.0	1,495.5	0.27	0.081	1.19	0.364	0.06	0.018	1.49	0.454	0.01	0.003
8/9	E, F	13,191.8	1,225.6	0.33	0.099	1.46	0.444	0.07	0.022	1.82	0.555	0.01	0.003
9/10	E	6,638.9	616.8	0.65	0.197	2.89	0.881	0.14	0.044	3.62	1.102	0.02	0.006
10/11	G, H	3,755.2	348.9	1.15	0.349	5.11	1.558	0.25	0.077	6.39	1.948	0.04	0.011
Reach Average				0.51	0.155	2.27	0.691	0.11	0.034	2.83	0.864	0.02	0.005
Appleton to Little Rapids Reach													
11/12	I, J, K	4,368.6	405.9	0.98	0.300	4.40	1.340	0.22	0.066	5.49	1.675	0.03	0.010
12/14	L through R	6,230.0	578.8	0.69	0.210	3.08	0.939	0.15	0.046	3.85	1.174	0.02	0.007
14/15	S	5,788.9	537.8	0.74	0.226	3.32	1.011	0.16	0.050	4.15	1.264	0.02	0.007
15/16	T, U	6,219.3	577.8	0.69	0.211	3.09	0.941	0.15	0.047	3.86	1.176	0.02	0.007
16/17	V, W, X	8,952.3	831.7	0.48	0.146	2.14	0.654	0.11	0.032	2.68	0.817	0.02	0.005
17/18	W, X, Y, Z	7,865.6	730.7	0.55	0.167	2.44	0.744	0.12	0.037	3.05	0.930	0.02	0.005
18/19	AA, BB, CC	4,917.3	456.8	0.87	0.267	3.90	1.190	0.19	0.059	4.88	1.488	0.03	0.009
19/20	—	3,497.0	324.9	1.23	0.375	5.49	1.673	0.27	0.083	6.86	2.092	0.04	0.012
20/21	—	4,573.0	424.8	0.94	0.287	4.20	1.280	0.21	0.063	5.25	1.600	0.03	0.009
21/22	DD	7,026.3	652.8	0.61	0.187	2.73	0.833	0.14	0.041	3.42	1.041	0.02	0.006
Reach Average				0.78	0.238	3.48	1.060	0.17	0.052	4.35	1.326	0.03	0.008
Little Rapids to De Pere Reach													
22/23	EE	10,200.5	947.7	0.42	0.128	1.88	0.574	0.09	0.028	2.35	0.717	0.01	0.004
23/24	EE	11,642.3	1,081.6	0.37	0.113	1.65	0.503	0.08	0.025	2.06	0.628	0.01	0.004
24/25	EE	10,942.9	1,016.6	0.39	0.120	1.75	0.535	0.09	0.026	2.19	0.668	0.01	0.004
25/26	EE	10,609.4	985.6	0.41	0.124	1.81	0.552	0.09	0.027	2.26	0.690	0.01	0.004
26/27	EE through HH	10,641.6	988.6	0.40	0.123	1.80	0.550	0.09	0.027	2.26	0.687	0.01	0.004
Reach Average				0.40	0.122	1.78	0.543	0.09	0.027	2.22	0.678	0.01	0.004
De Pere to Green Bay Reach													
28/29	SMU 20–25	18,593.3	1,727.4	0.23	0.070	1.03	0.315	0.05	0.016	1.29	0.393	0.01	0.002
29/30	SMU 25–31	12,083.5	1,122.6	0.36	0.108	1.59	0.484	0.08	0.024	1.99	0.605	0.01	0.004
30/31	SMU 32–37	13,751.3	1,277.5	0.31	0.095	1.40	0.426	0.07	0.021	1.75	0.532	0.01	0.003
31/32	SMU 38–43	16,947.0	1,574.4	0.25	0.077	1.13	0.345	0.06	0.017	1.42	0.432	0.01	0.003
32/33	SMU 44–49	20,002.8	1,858.3	0.21	0.066	0.96	0.293	0.05	0.014	1.20	0.366	0.01	0.002
33/34	SMU 50–55	15,698.8	1,458.5	0.27	0.083	1.22	0.373	0.06	0.018	1.53	0.466	0.01	0.003
34/35	SMU 56–61	20,519.3	1,906.3	0.21	0.064	0.94	0.285	0.05	0.014	1.17	0.357	0.01	0.002
35/36	SMU 62–67	20,056.6	1,863.3	0.21	0.065	0.96	0.292	0.05	0.014	1.20	0.365	0.01	0.002
36/37	SMU 68–73	20,551.6	1,909.3	0.21	0.064	0.93	0.285	0.05	0.014	1.17	0.356	0.01	0.002
37/38	SMU 73–79	19,389.5	1,801.3	0.22	0.068	0.99	0.302	0.05	0.015	1.24	0.377	0.01	0.002
38/39	SMU 80–85	14,891.8	1,383.5	0.29	0.088	1.29	0.393	0.06	0.019	1.61	0.491	0.01	0.003
39/40	SMU 86–91	16,387.0	1,522.0	0.26	0.080	1.17	0.357	0.06	0.018	1.46	0.446	0.01	0.003
Reach Average				0.25	0.077	1.13	0.346	0.06	0.017	1.42	0.432	0.01	0.003
Entire River Averages				0.45	0.137	2.01	0.612	0.10	0.030	2.51	0.766	0.01	0.004

Notes:

¹ The average, peak, and low flow velocities listed are from USGS records for the Rapide Croche gauging station, #04084500.

² Cross-sectional areas obtained from Velleux & Endicott, 1994 and WDNR, 1995.

Table 2-6 Lower Fox River Discharge Results: Rapide Croche Gauging Station

Summary of Flow Conditions for Water Years 1918 to 1997	Discharge (m³/s)	Discharge (cfs)	Date	
Daily Average	122	4,314	—	
Highest Daily Mean	680	24,000	April 18, 1952	
Lowest Daily Mean	4	138	August 2, 1936	
Monthly Mean Maximum	206	7,286	April	
Monthly Mean Minimum	74	2,609	August	
Monthly Discharge Results				
Month	Average (m³/s)	(cfs)	Minimum (m³/s)	Maximum (m³/s)
January	116	4,082	31	269
February	117	4,126	30	340
March	146	5,156	25	603
April	206	7,286	22	680
May	171	6,048	23	669
June	137	4,821	17	603
July	96	3,372	18	530
August	74	2,609	4	419
September	81	2,872	8	510
October	94	3,315	6	516
November	116	4,084	15	445
December	115	4,043	32	363

Note:

A water year runs from October 1 through September 30.

Table 2-7 Lower Fox River and Green Bay Maximum PCB Sampling Depth

Location	PCB Mass and Percent in System*	Contaminated Sediment Volume and Percent in System*
Little Lake Butte des Morts Reach	1,540 kg (1.6%)	1.35 million m ³ (0.29%)
Appleton to Little Rapids Reach	94 kg (0.1%)	0.18 million m ³ (0.04%)
Little Rapids to De Pere Reach	980 kg (1.0%)	1.71 million m ³ (0.36%)
De Pere to Green Bay Reach	25,984 kg (26.8%)	5.52 million m ³ (1.16%)
Green Bay Zone 2	32,013 kg (33.1%)	39.5 million m ³ (8.33%)
Green Bay Zone 3	35,243 kg (36.4%)	397 million m ³ (83.72%)
Green Bay Zone 4	925 kg (1.0%)	28.9 million m ³ (6.10%)
Total	96,784 kg	474.16 million m³

Note:

* Includes sediments containing PCB concentrations greater than 50 µg/kg.

**Table 2-8 Lower Fox River Mouth Gauging Station Results
(1989–1997)**

Summary of Flow Conditions	Discharge m ³ /s (cfs)	Date (or month)
Daily Average: WY 1989–1997	149 (5,262)	—
Highest Daily Mean: WY 1989–1997	957 (33,800)	June 23, 1990
Lowest Daily Mean: WY 1989–1997	-92 (-3,250)	November 4, 1990
Monthly Mean Maximum: WY 1989–1997	210 (7,420)	April
Monthly Mean Minimum: WY 1989–1997	103 (3,635)	September
Monthly Mean Maximum: WY 1997	244 (8,620)	April
Monthly Mean Minimum: WY 1997	56 (1,980)	September
Daily Maximum: WY 1997	419 (14,800)	March 28, 1997
Daily Minimum: WY 1997	-15 (-530)	May 28, 1997

Table 2-9 Total Suspended Solid (TSS) Loads from the Lower Fox River into Green Bay

Sampling Point	River Discharge		Total Suspended Solids (TSS)		
	(m ³ /s)	(cfs)	(mg/L)	(MT/year)	(Ton/year)
<i>Mean Values from WDNR, 1995</i>					
<i>Lower Fox River Reaches</i>					
Menasha gauge*	140	4,938	7.7	33,968	37,365
Neenah gauge*	80	2,809	17	42,661	46,927
Appleton gauge	93	3,279	23	67,375	74,113
Kaukauna gauge*	85	3,009	26	69,892	76,881
Little Rapids gauge**	87	3,058	52	142,060	156,266
De Pere gauge	85	3,003	30	80,484	88,532
<i>Mean Values from Gailani et al., 1991</i>					
<i>De Pere to Green Bay Reach</i>					
De Pere dam	105	3,700	30	99,164	109,081
River mouth	105	3,700	6	19,833	21,816
Sampling Point	River Discharge		Total Suspended Solids		
	m ³ /s	cfs	mg/L	MT/year	
De Pere dam	105	3,706.50	30	99,338	
	280	9,884.00	75	662,256	
	432	15,249.60	190	2,588,475	
River mouth	105	3,706.50	6	19,868	
	280	9,884.00	57	503,315	
	432	15,249.60	130	1,771,062	

Notes:

* The stream flow result for this station is actually the flow at the Appleton station

** The stream flow result for this station is actually the flow at the De Pere station

MT - metric tons.

Table 2-10 Results of Sediment Time Trends Analysis on the Lower Fox River

Deposit Group	Depth Range (cm)	Log ₁₀ (PCB) Time Trend Slope Estimate	WSEV Standard Error	WSEV p-Value	Estimated Annual Compound Percent Increase (Decrease) in PCB Level	Estimated Annual Compound Percent Increase (Decrease) in PCB Level 95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
<i>Little Lake Butte des Morts Reach</i>							
AB	0-10	-0.0970	0.0348	0.0131	-20.0252	-32.5184	-5.2190
	10-30	-0.0213	0.0647	0.7535	-4.7785	-33.8607	37.0914
	30-50	-0.0144	0.1113	0.8995	-3.2580	-44.9528	70.0179
C	0-10	-0.0612	0.0342	0.1481	-13.1527	-30.2218	8.0920
	10-30	0.0317	0.0770	0.7018	7.5669	-34.2398	75.9520
POG	0-10	-0.0893	0.0567	0.1900	-18.5943	-43.3347	16.9478
D	0-10	-0.0755	0.0317	0.0307	-15.9649	-28.0617	-1.8339
	10-30	0.3168	0.0454	0.0009	107.3860	58.5121	171.3292
F	0-10	-0.0373	0.0136	0.0252	-8.2308	-14.6158	-1.3684
	10-30	-0.0760	0.0749	0.3246	-16.0577	-41.6741	20.8094
GH	0-10	-0.1244	0.0541	0.0443	-24.9124	-43.1170	-0.8818
<i>Appleton to Little Rapids Reach</i>							
IMOR	0-10	0.0412	0.0255	0.1810	9.9476	-6.5658	29.3796
N Pre-dredge	0-10	-0.0281	0.0065	0.0233	-6.2555	-10.6450	-1.6504
	10-30	0.0572	0.0440	0.2061	14.0840	-7.4773	40.6698
	30-50	0.0846	0.0932	0.3877	21.5002	-25.2171	97.4021
VCC	0-10	-0.0582	0.0275	0.0878	-12.5329	-25.6543	2.9044
	10-30	-0.1537	0.0164	0.0000	-29.8115	-35.4198	-23.7163
	30-50	-0.0060	0.0151	0.6984	-1.3741	-8.7096	6.5507
<i>Little Rapids to De Pere Reach</i>							
Upper EE	0-10	-0.0447	0.0435	0.3618	-9.7861	-31.6823	19.1279
	10-30	-0.0944	0.0429	0.0554	-19.5286	-35.6413	0.6181
	30-50	-0.0712	0.0536	0.2173	-15.1118	-35.8039	12.2499
Lower EE	0-10	-0.0682	0.0193	0.0387	-14.5308	-25.8145	-1.5310
	10-30	-0.0759	0.0390	0.0695	-16.0283	-30.5817	1.5761
	30-50	0.0900	0.0330	0.0213	23.0209	3.8593	45.7177
FF	0-10	-0.0549	0.0557	0.3400	-11.8664	-32.9367	15.8238
	10-30	-0.0962	0.0390	0.0389	-19.8690	-34.8569	-1.4327
GGHH	0-10	-0.0394	0.0231	0.1643	-8.6641	-21.2286	5.9045
	10-30	-0.0182	0.0596	0.7631	-4.0982	-27.7264	27.2546
	30-50	0.1762	0.1008	0.1188	50.0238	-12.1753	156.2737
	50-100	0.1012	0.0700	0.1586	26.2311	-9.1644	75.4191
	100+	0.0365	0.0249	0.1587	8.7556	-3.5026	22.5710
<i>De Pere to Green Bay Reach</i>							
SMU Group 20-25	0-10	-0.0528	0.0231	0.0838	-11.4462	-23.5795	2.6135
	10-30	-0.0556	0.0750	0.4796	-12.0176	-40.9140	31.0108
	30-50	-0.0580	0.0322	0.1016	-12.4973	-25.8079	3.2014
	50-100	-0.0847	0.1058	0.4306	-17.7243	-50.1718	35.8538
26-49	0-10	-0.0608	0.0109	0.0000	-13.0594	-17.4071	-8.4827
	10-30	-0.2882	0.1440	0.0764	-48.5003	-75.6756	9.0355
	50-100	0.1957	0.1419	0.2399	56.9258	-36.6450	288.6939
	100+	0.0177	0.1548	0.9146	4.1538	-61.2934	180.2628
50-67	0-10	-0.0998	0.0345	0.0136	-20.5271	-33.1743	-5.4864
	10-30	0.0912	0.0649	0.1800	23.3725	-10.2622	69.6138
	50-100	0.3677	0.0684	0.0030	133.1723	55.5425	249.5468
	100+	-0.1963	0.2223	0.4112	-36.3596	-81.8094	122.6480
68-91	0-10	-0.2208	0.0944	0.1013	-39.8569	-69.8854	20.1142
	10-30	-0.1685	0.0765	0.0550	-32.1613	-54.4475	1.0282
92-115	0-10	0.0413	0.0426	0.3493	9.9747	-10.9075	35.7515

Table 2-11 Results of Fish Time Trends Analysis on the Lower Fox River

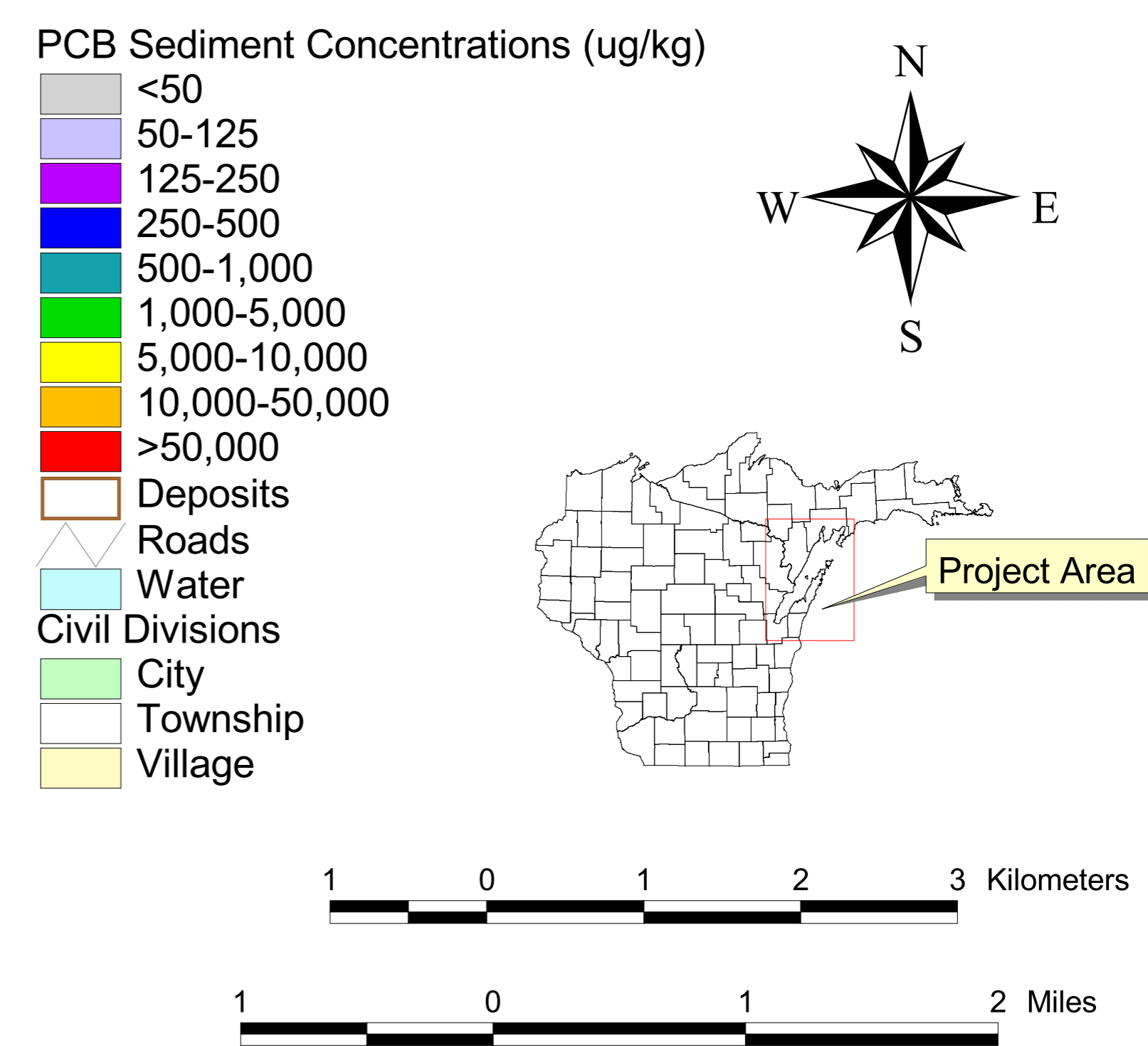
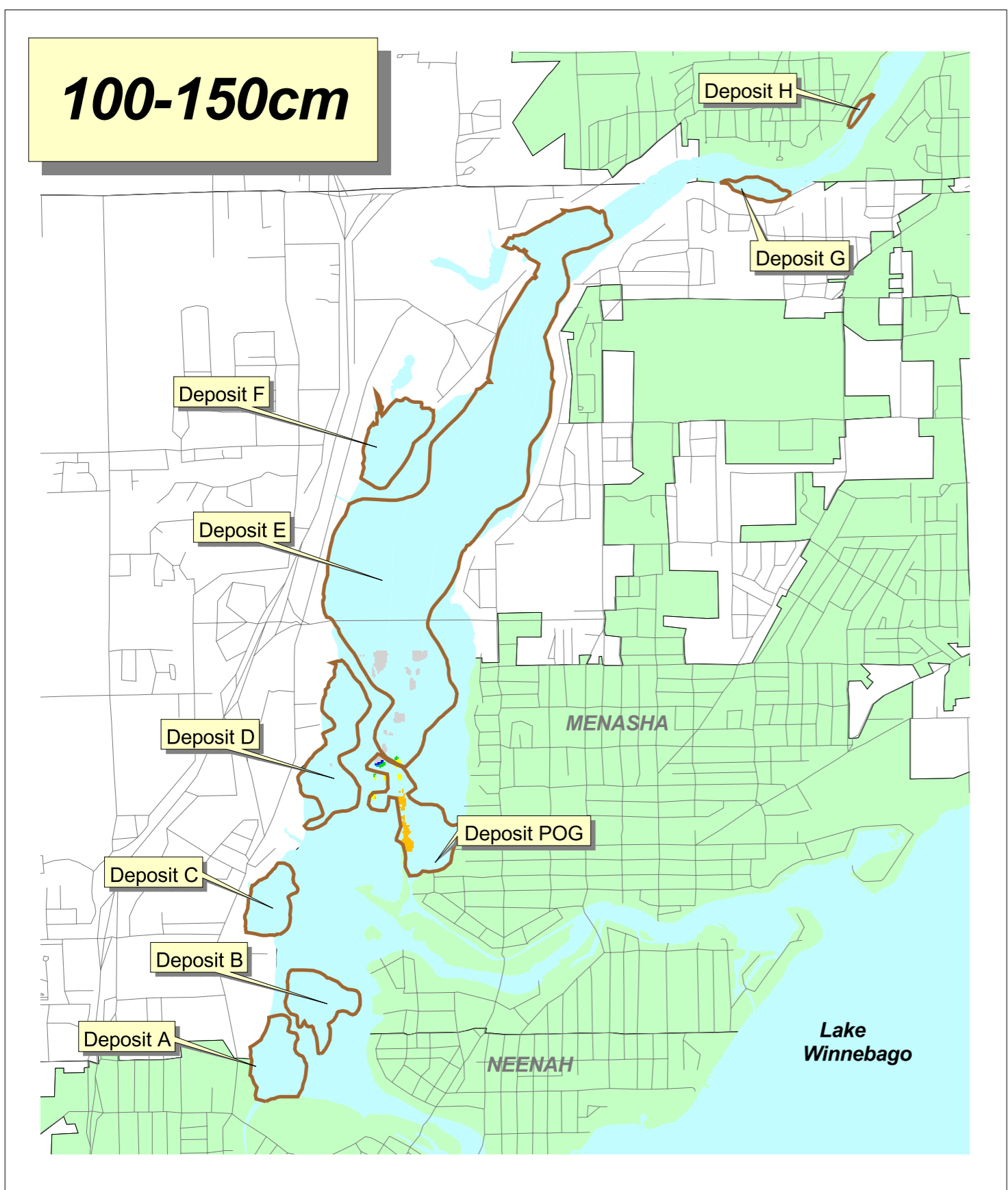
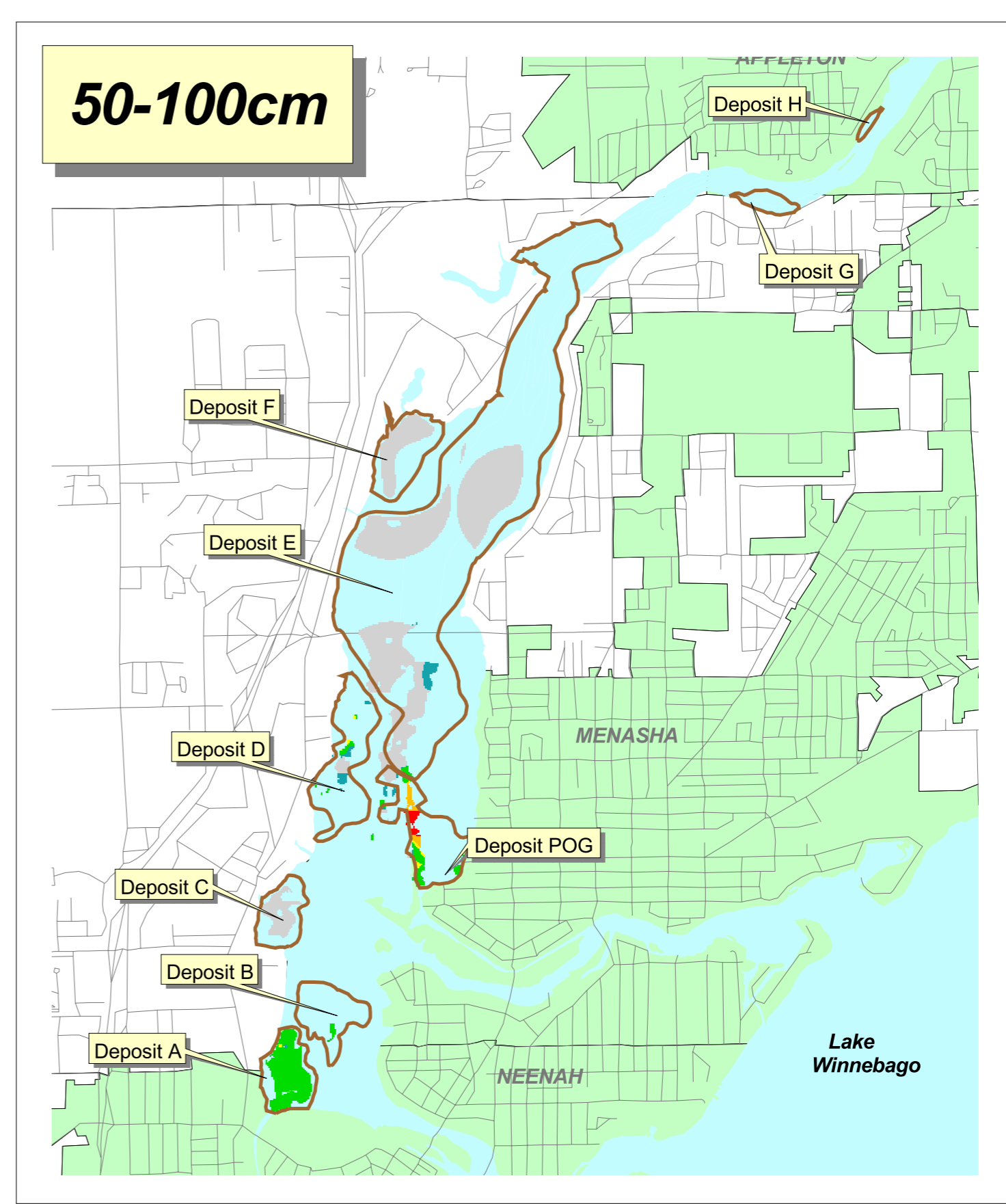
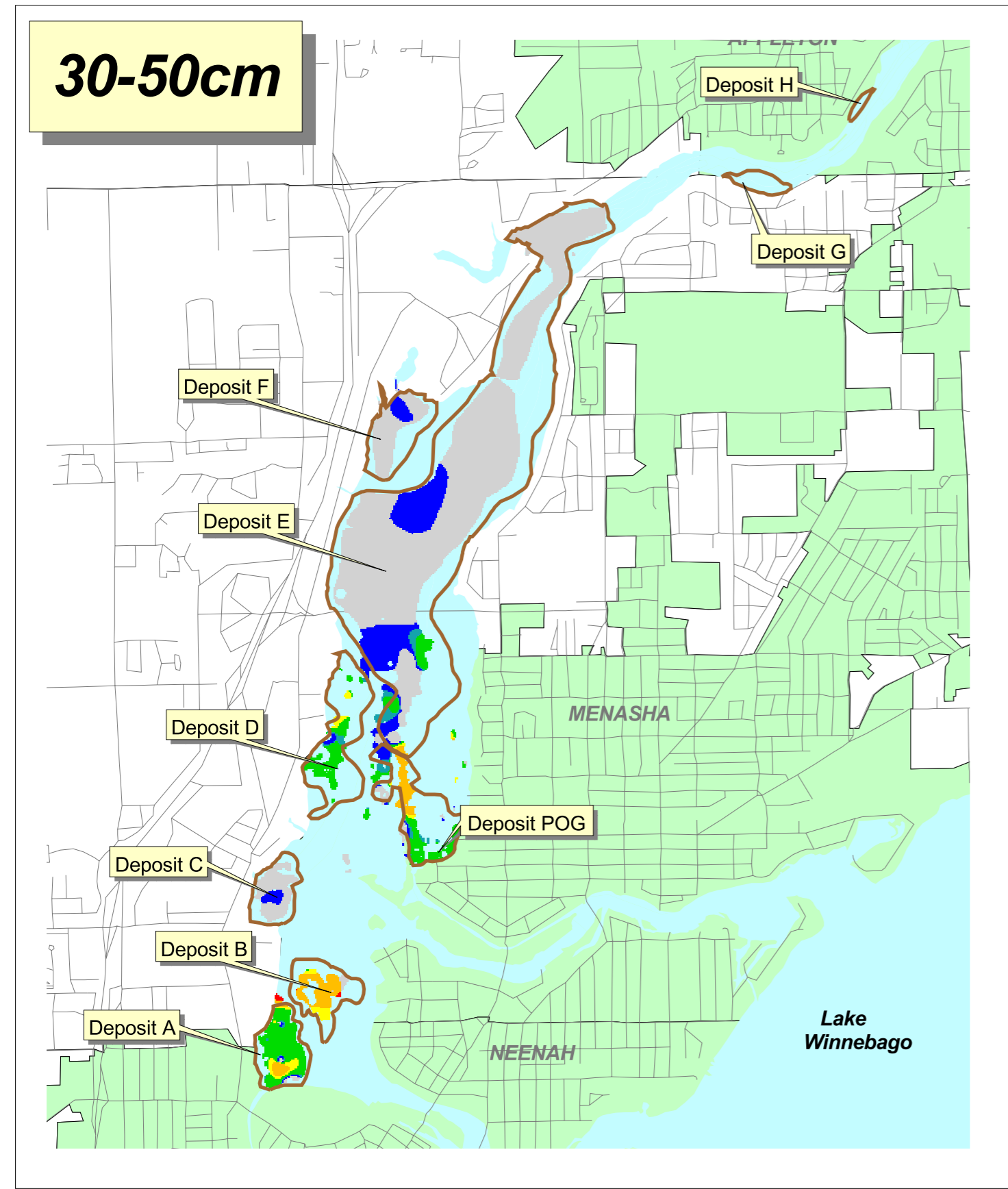
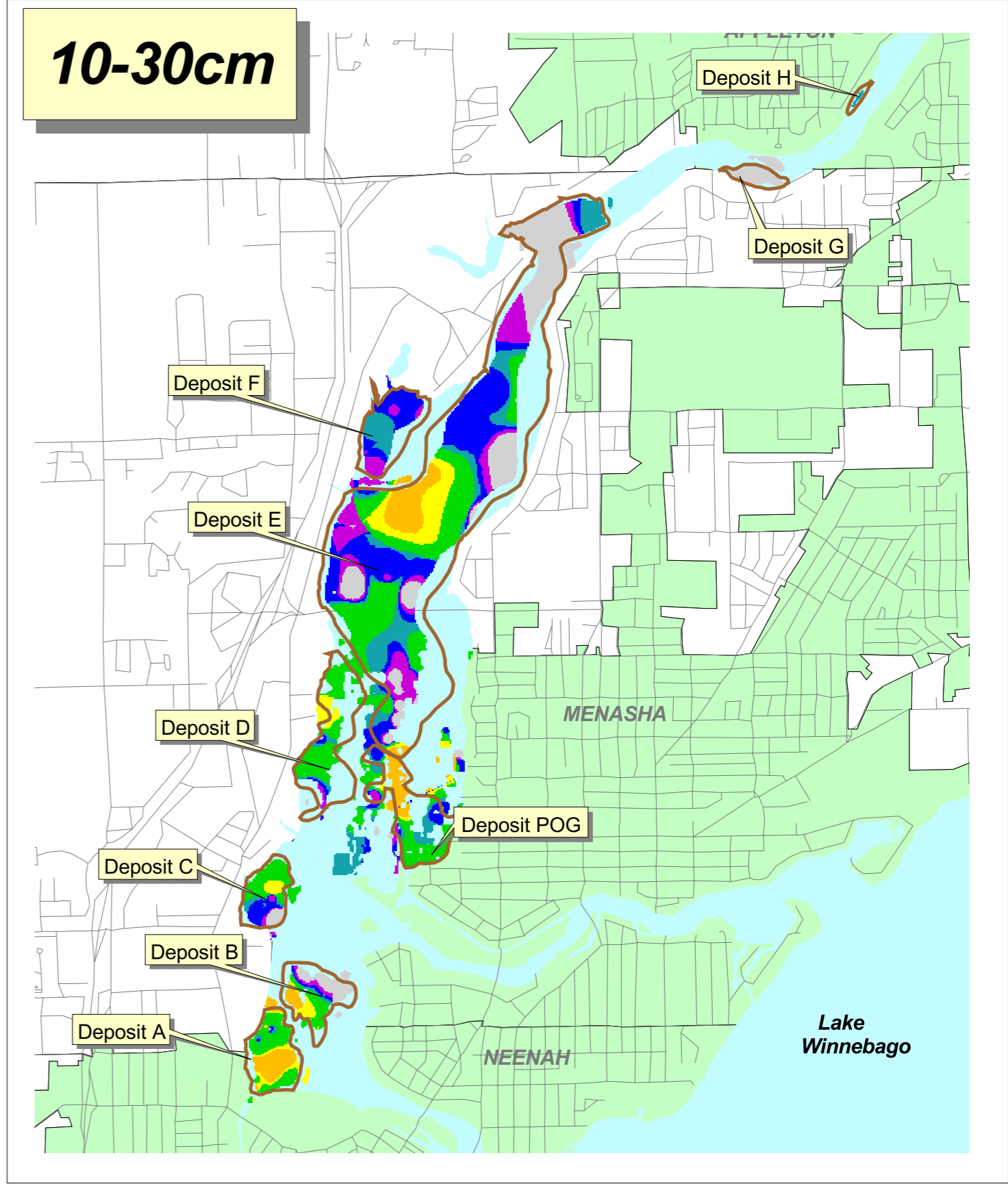
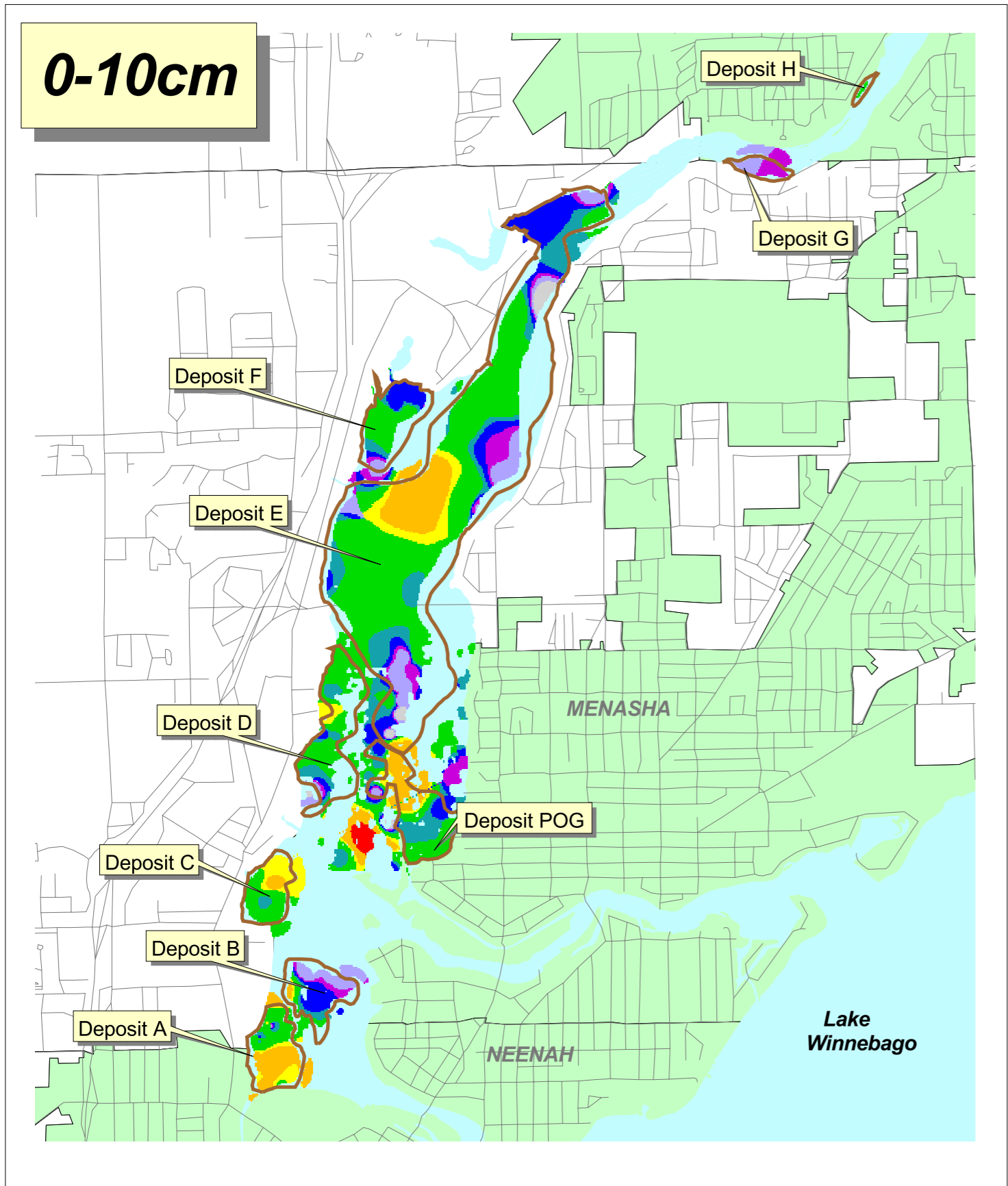
Species	Type	Sample Size	Year of Breakpoint	Percent Change per Year	95% Confidence Interval		p-Value
					LCL	UCL	
Little Lake Butte des Morts							
Carp	fillet on skin	55	1979	-6.15	-10.9	-1.1	0.0177
Carp	whole fish	40	1987	0.71	-12.3	15.6	0.9172
Northern Pike	fillet on skin	19		-11.83	-16.7	-6.7	0.0003
Walleye	fillet on skin	63	1990	3.44	-7.8	16.0	0.5576
Walleye	whole fish	18	1987	21.47	-3.5	52.9	0.0874
Yellow Perch	fillet on skin	34	1981	0.73	-5.0	6.8	0.8025
Combined				-4.86			0.0055
Appleton to Little Rapids							
Walleye	fillet on skin	30		-9.97	-15.7	-3.9	0.0028
De Pere to Green Bay (Zone 1)							
Carp	whole fish	90	1995	21.76	2.2	45.0	0.0277
Gizzard Shad	whole fish	19		-5.07	-7.2	-2.9	0.0002
Northern Pike	fillet on skin	40		-9.95	-13.0	-6.8	<0.0001
Walleye	fillet on skin	120		-7.19	-8.7	-5.6	<0.0001
Walleye	whole fish	58		-8.11	-10.4	-5.8	<0.0001
White Bass	fillet on skin	58		-4.72	-7.5	-1.8	<0.0001
White Sucker	fillet on skin	44		-7.90	-10.3	-5.5	<0.0001
Combined				-6.89			<0.0001
Green Bay Zone 2							
Alewife	whole fish	44		-3.96	-7.8	0.0	0.0497
Carp	fillet on skin	28		-5.06	-11.8	2.2	0.1557
Carp	whole fish	57	1983	-15.54	-19.5	-11.4	<0.0001
Gizzard Shad	whole fish	32		5.91	1.2	10.8	0.0144
Yellow Perch	fillet on skin	19		-10.75	-16.8	-4.2	0.0038
Combined				-5.11			<0.0001

Table 2-12 Mass-weighted Combined Time Trend for 0 to 10 cm Depth by Reach

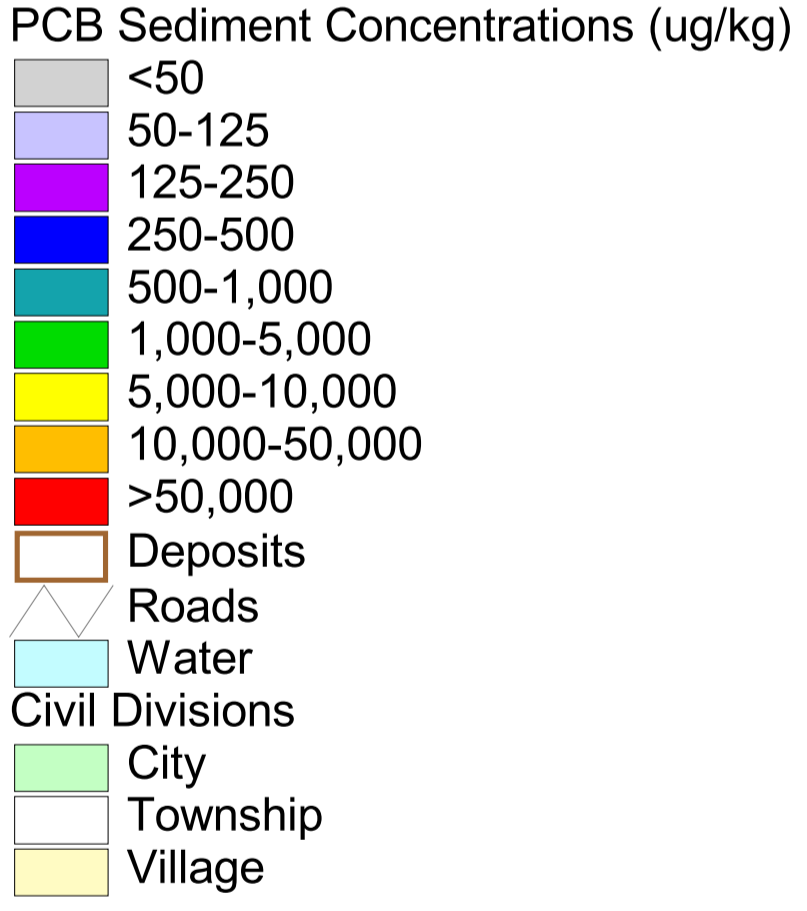
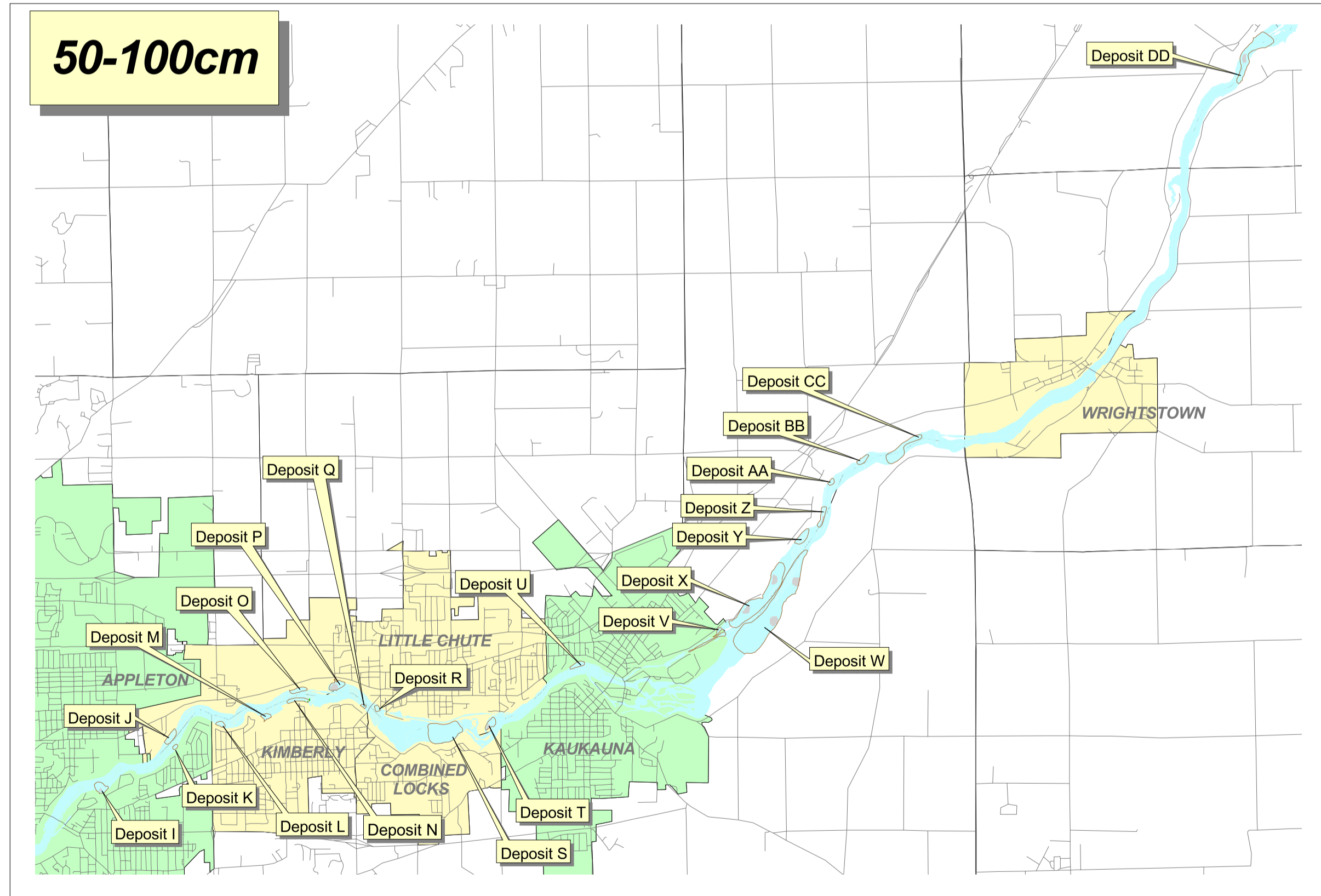
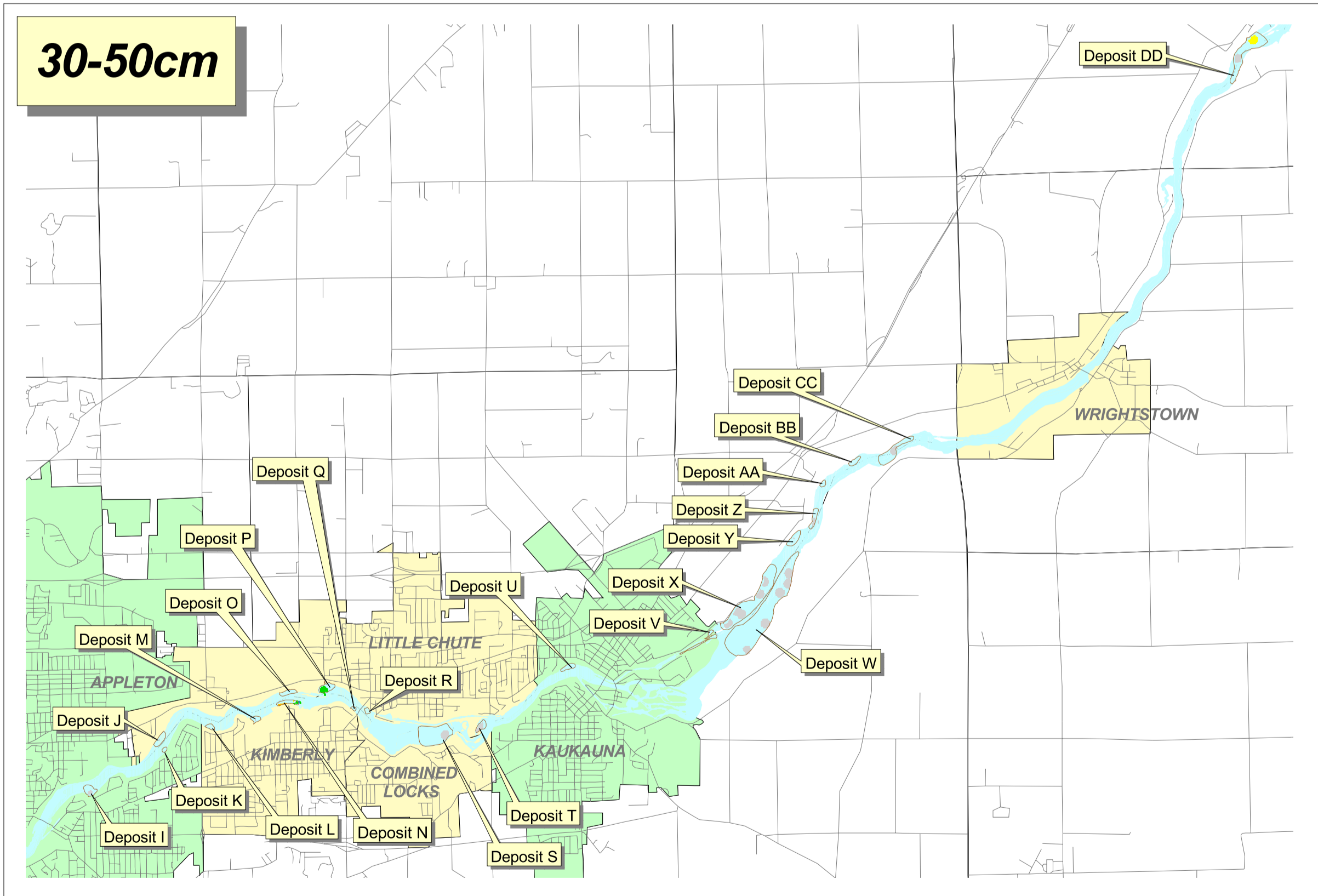
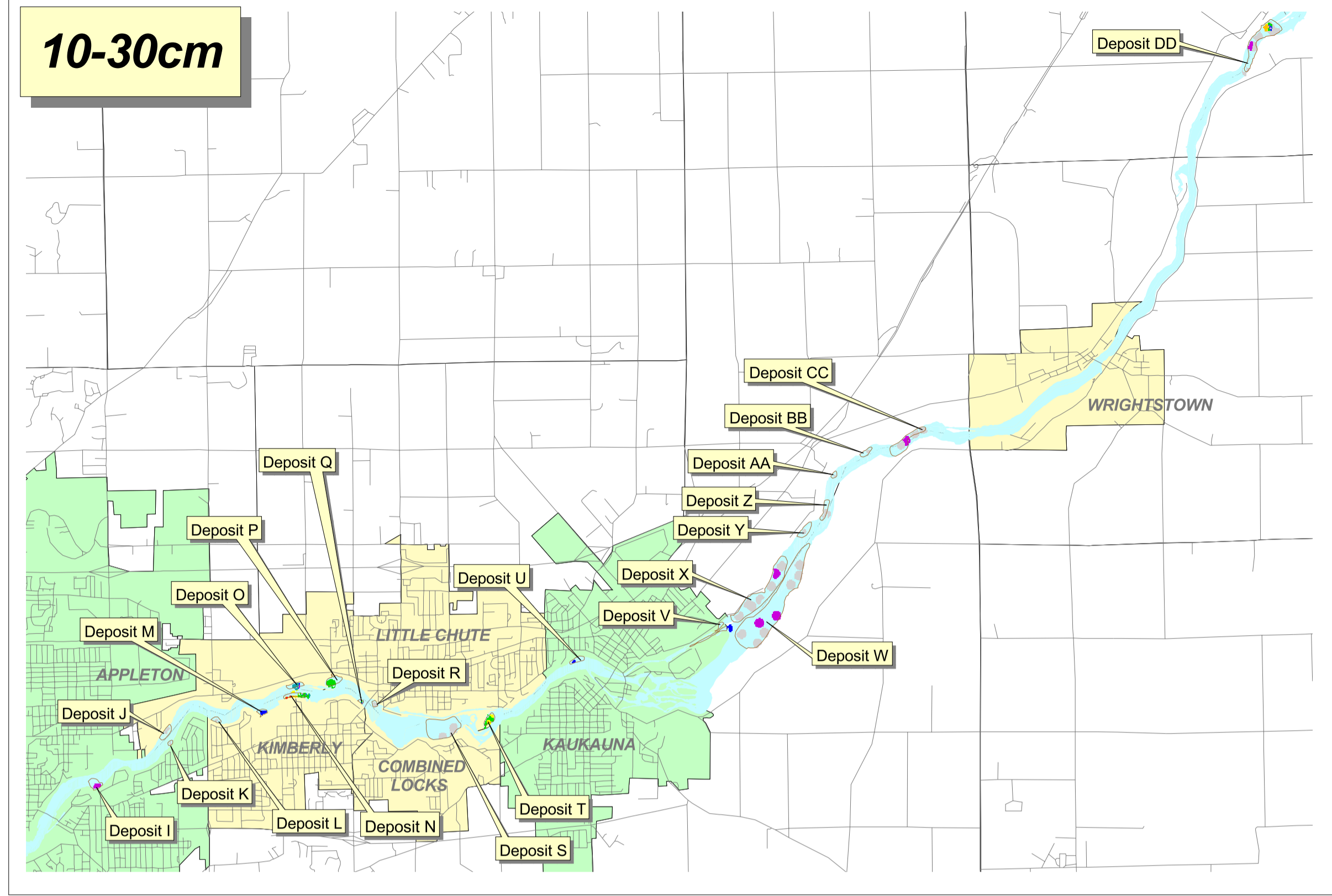
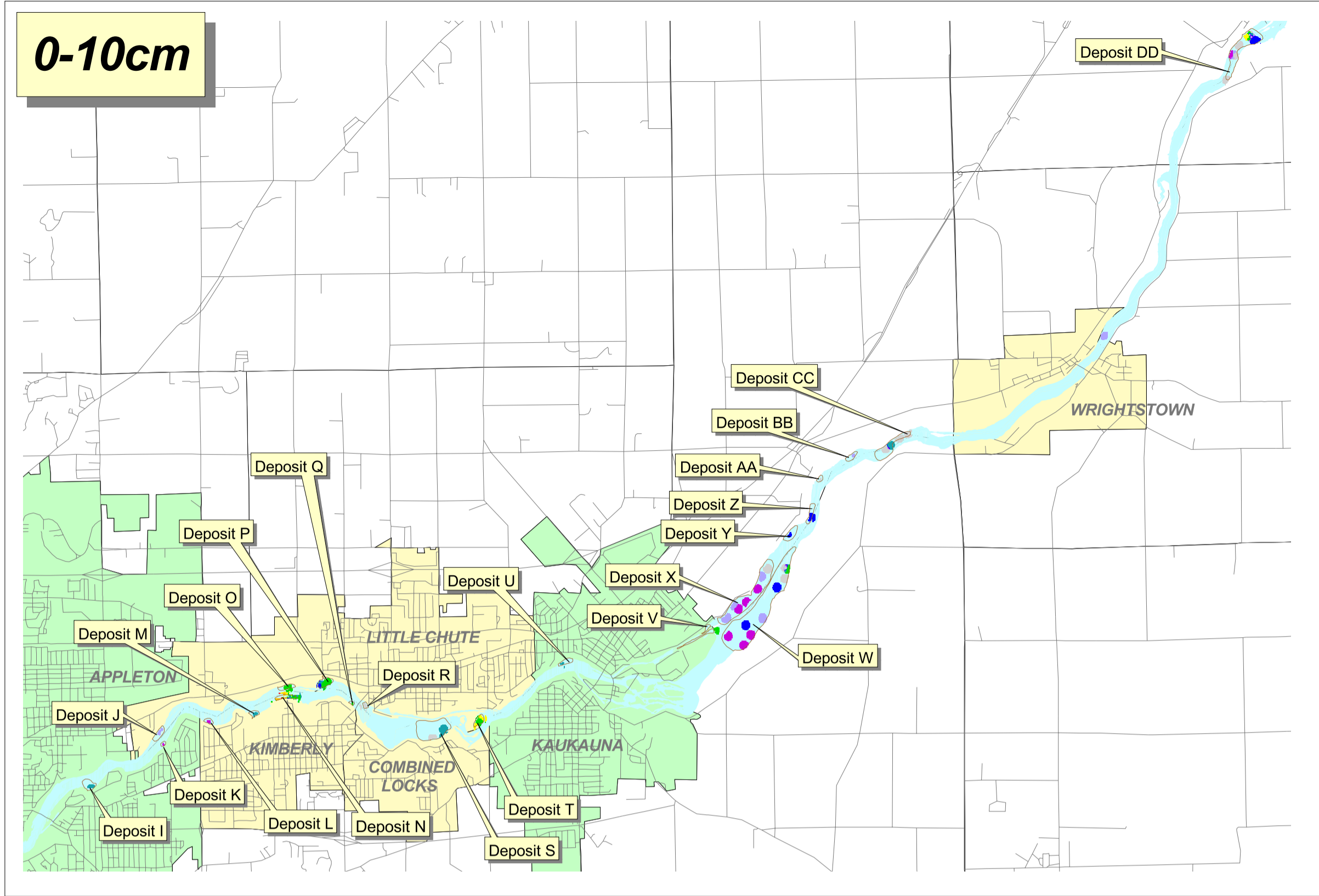
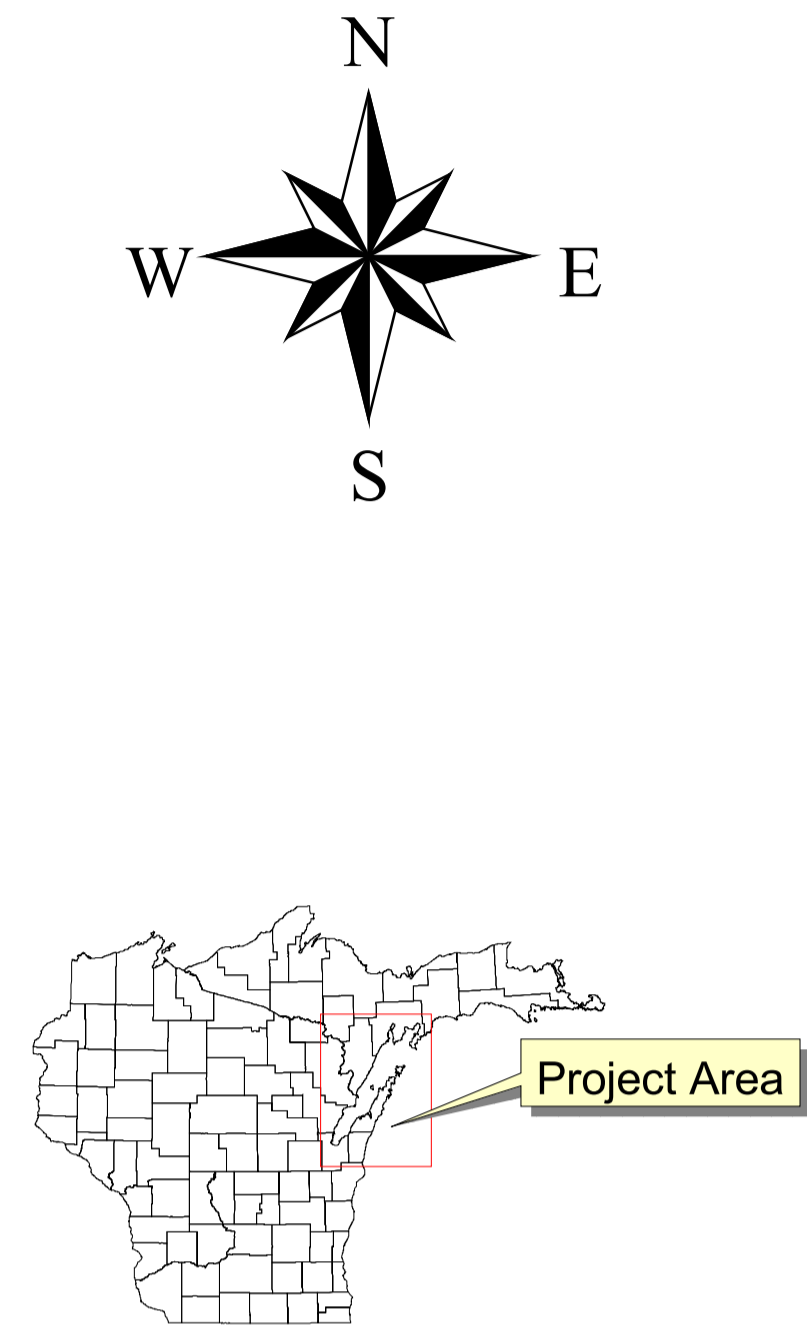
Deposit Group	Log ₁₀ (PCB) Time Trend Slope Estimate	WSEV Standard Error	PCB Mass (kg)	p-value	Annual Percent Change in PCB Concen- tration	Percent Change 95% Lower- bound	Percent Change 95% Upper- bound
<i>Little Lake Butte des Morts</i>							
AB	-0.09705	0.034798	71.7				
C	-0.06124	0.03423	25.4				
POG	-0.08935	0.056669	113.5				
D	-0.07554	0.031669	32.1				
F	-0.0373	0.013582	142.5				
GH	-0.12443	0.054119	15.7				
Reach, Combined	-0.07071	0.01831	400.9	0.0001***	-15.0	-21.8	-7.7
<i>Appleton</i>							
IMOR	0.041186	0.025457	13.7				
N Pre-dredge	-0.02805	0.006544	6.9				
VCC	-0.05816	0.02746	5.2				
Reach, Combined	-0.0025	0.01469	25.9	0.9	0.6	-5.9	7.5
<i>Little Rapids</i>							
Upper EE	-0.04473	0.043487	85.0				
Lower EE	-0.06819	0.019322	25.4				
FF	-0.05486	0.055669	36.7				
GGHH	-0.03936	0.023149	131.6				
Reach, Combined	-0.04567	0.018764	278.7	0.01*	-10.0	-17.3	-2.0
<i>De Pere</i>							
SMU Group 2025	-0.05279	0.02305	225.6				
SMU Group 2649	-0.06078	0.010894	356.8				
SMU Group 5067	-0.09978	0.034549	92.4				
SMU Group 6891	-0.22081	0.094396	72.1				
SMU Group 92115	0.041293	0.042639	37.1				
Reach, Combined	-0.07296	0.012829	784.0	<0.0001***	-15.5	-20.2	-10.4

Notes:* $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

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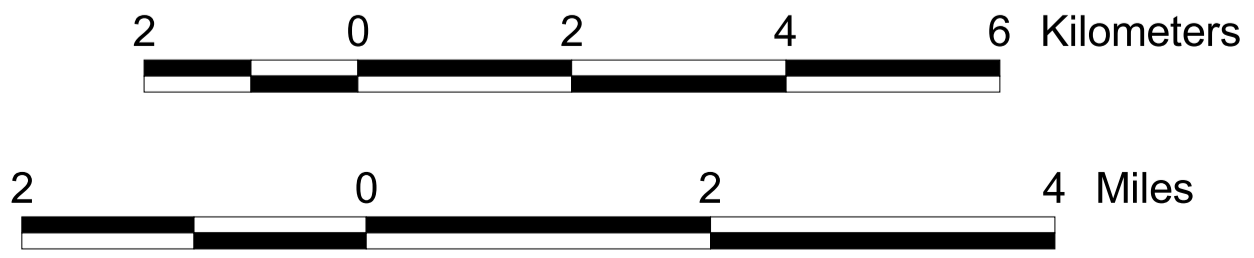


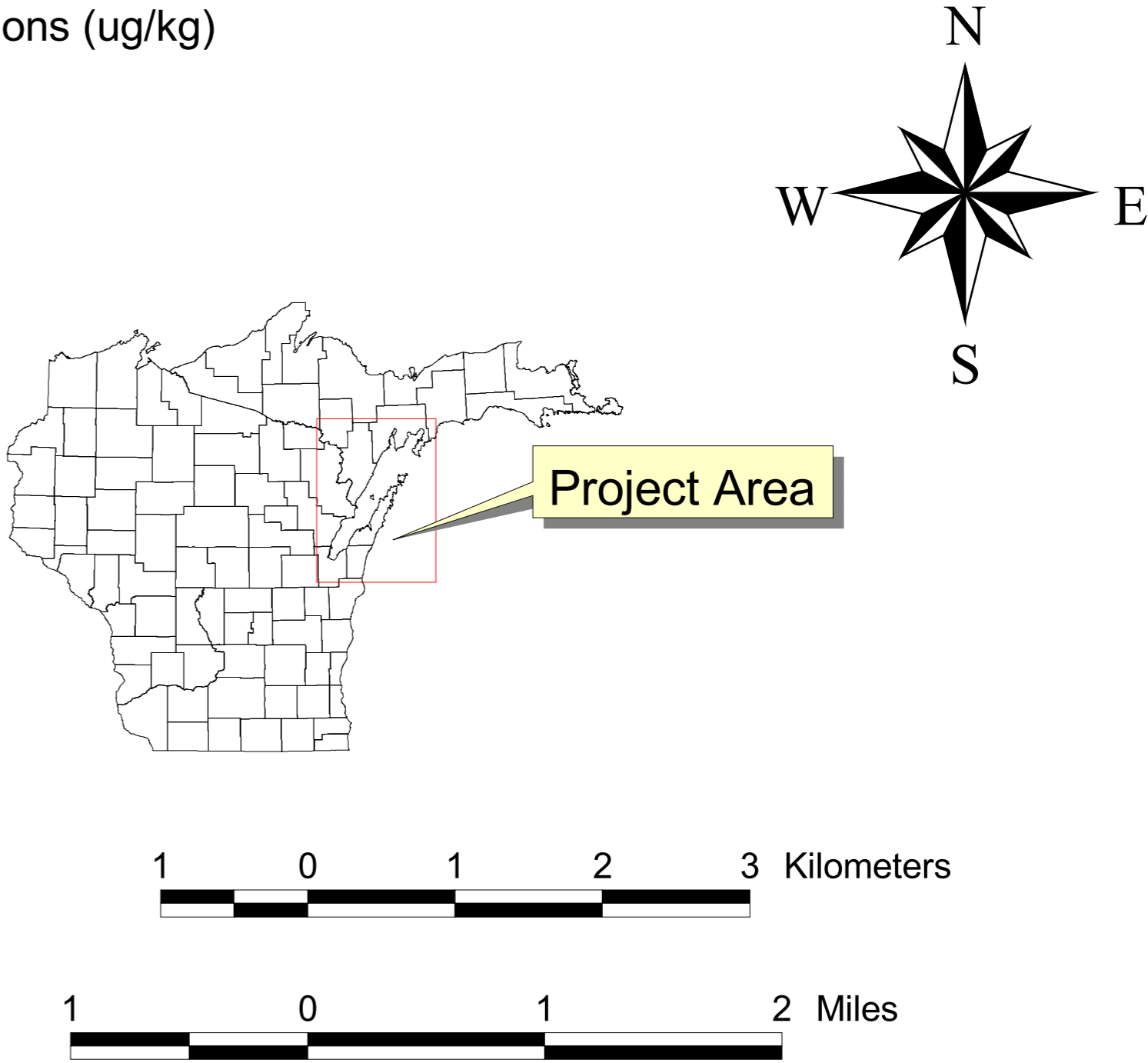
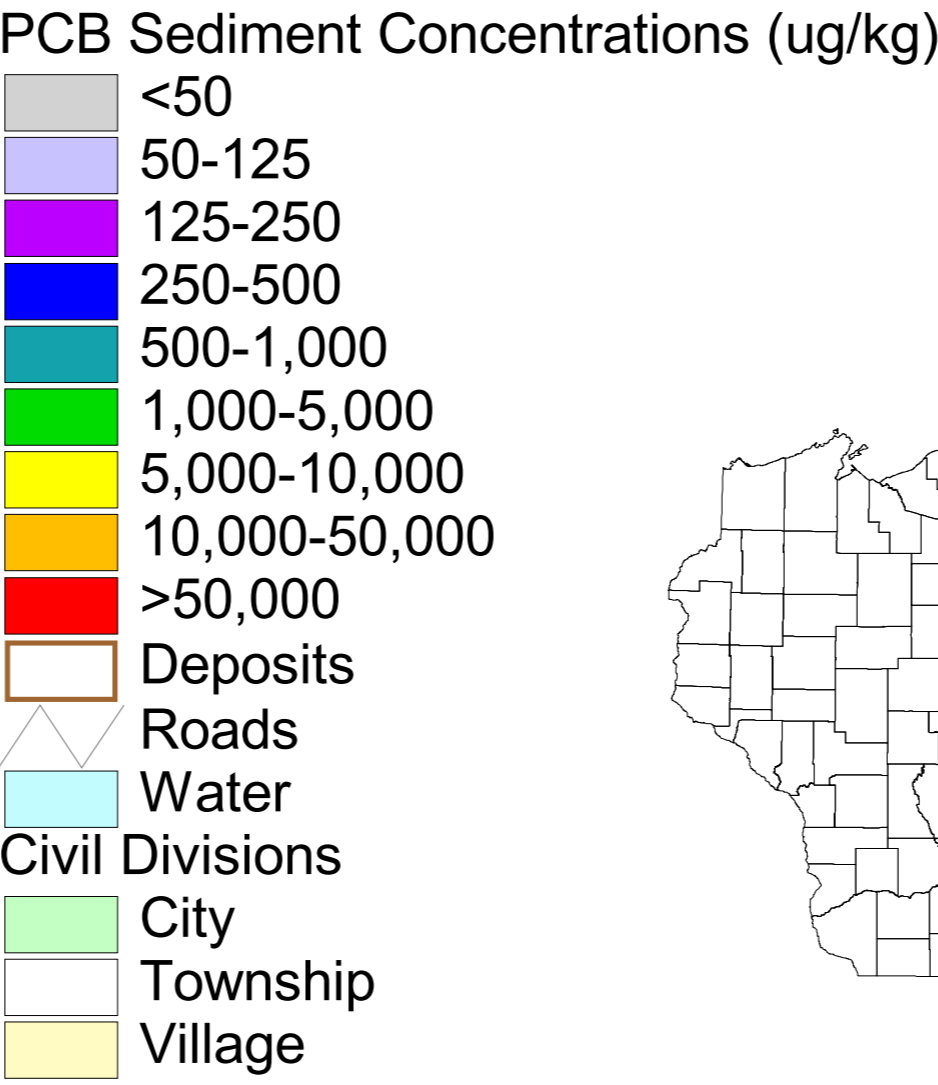
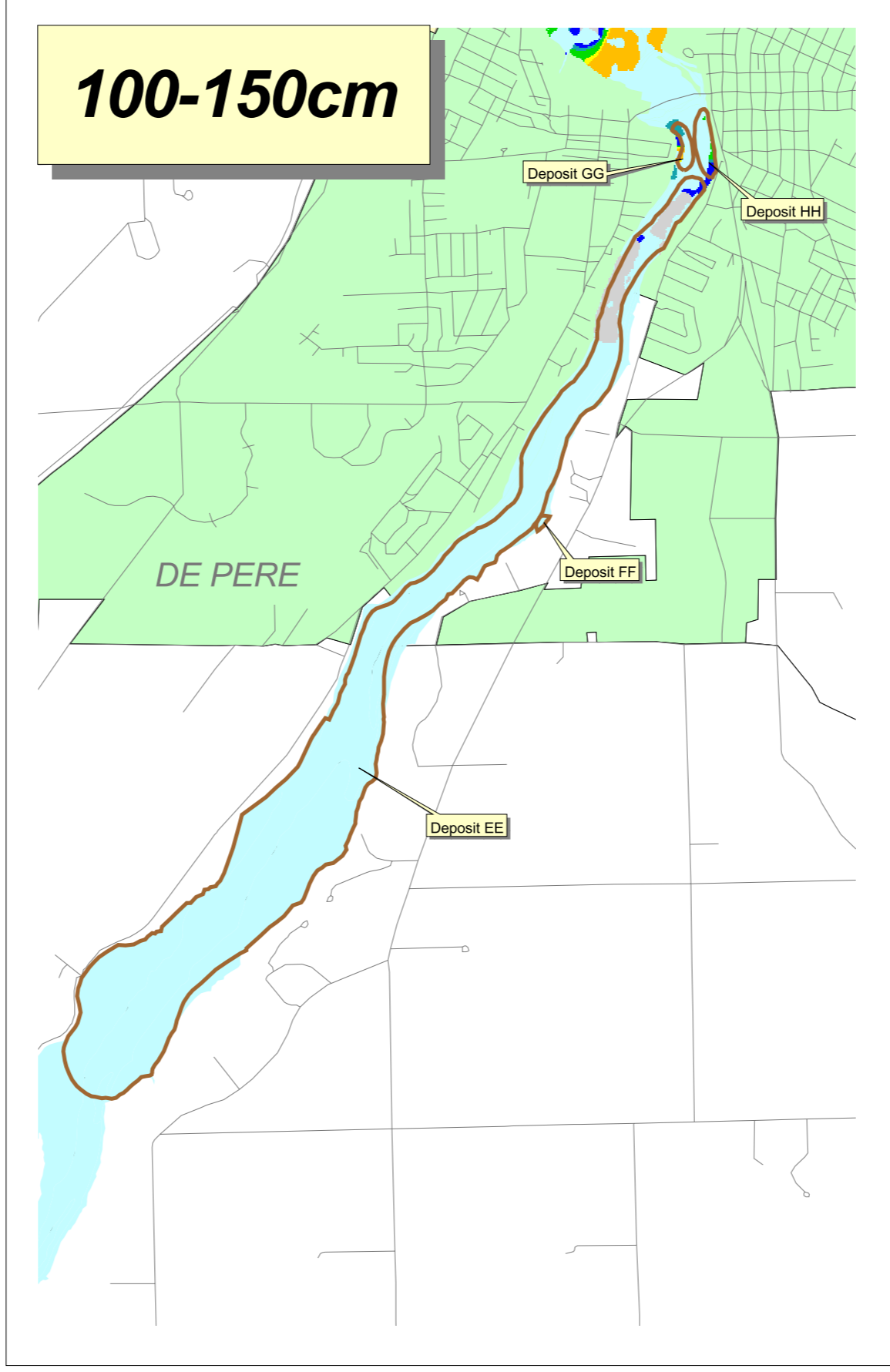
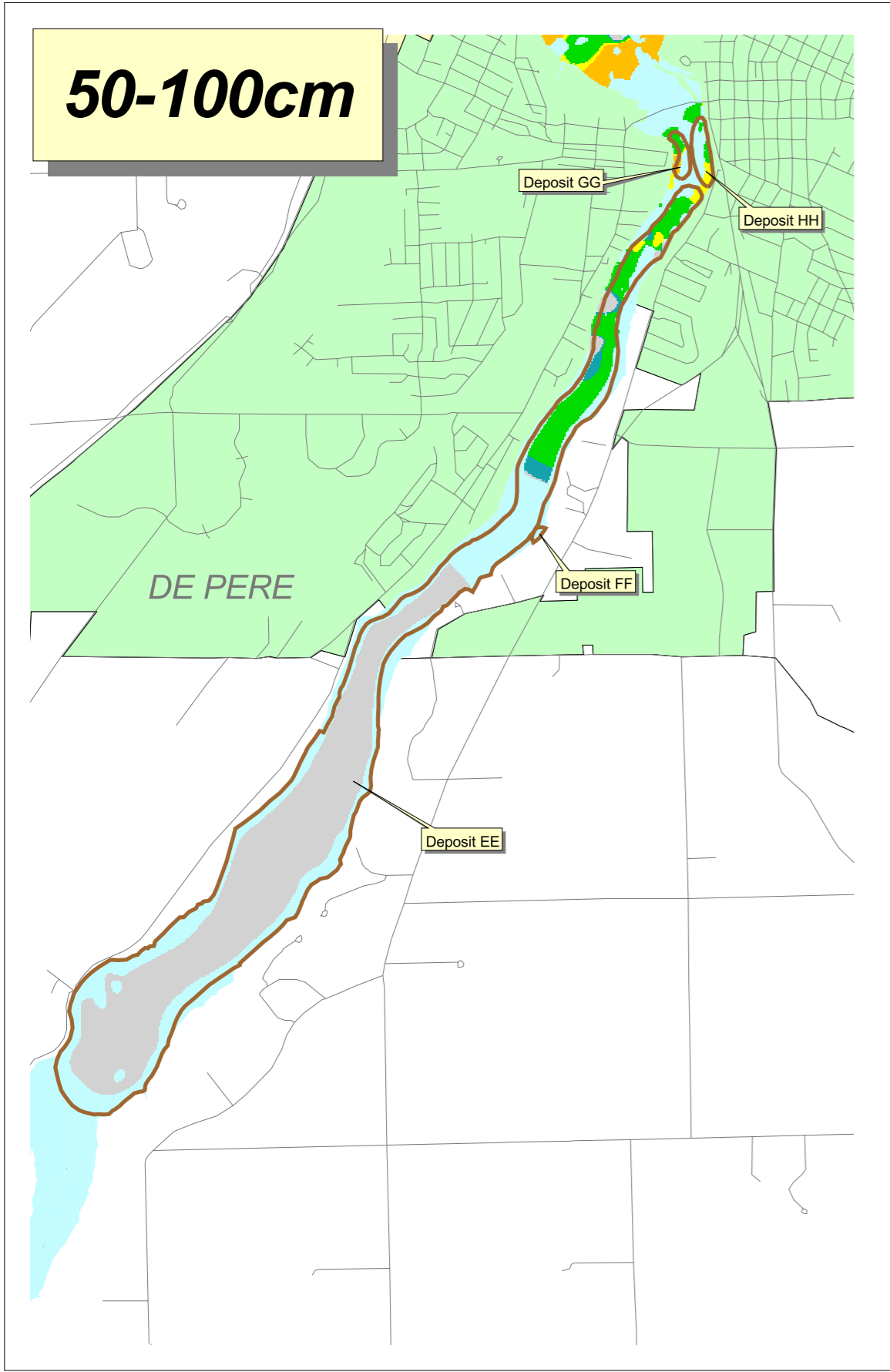
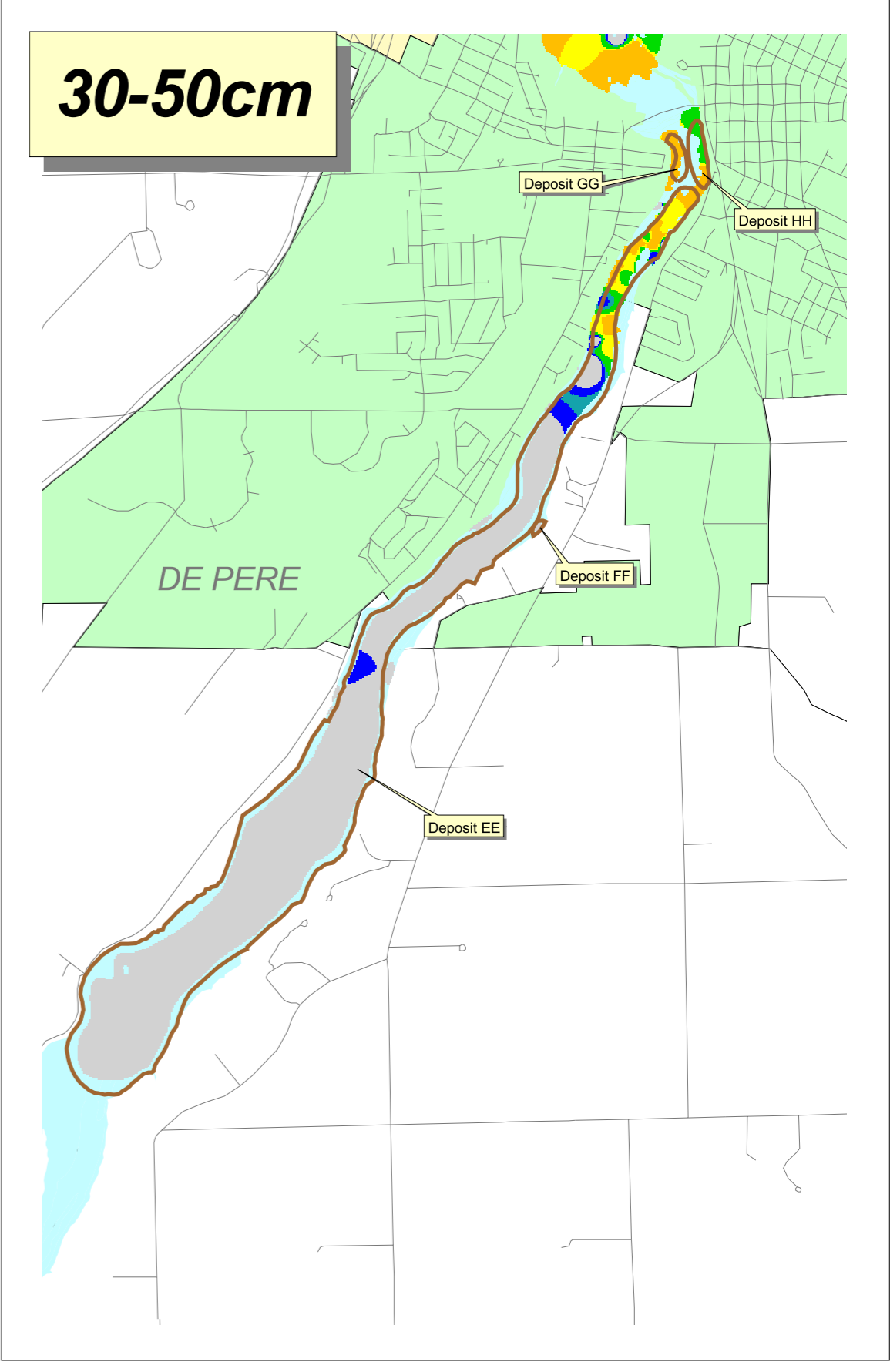
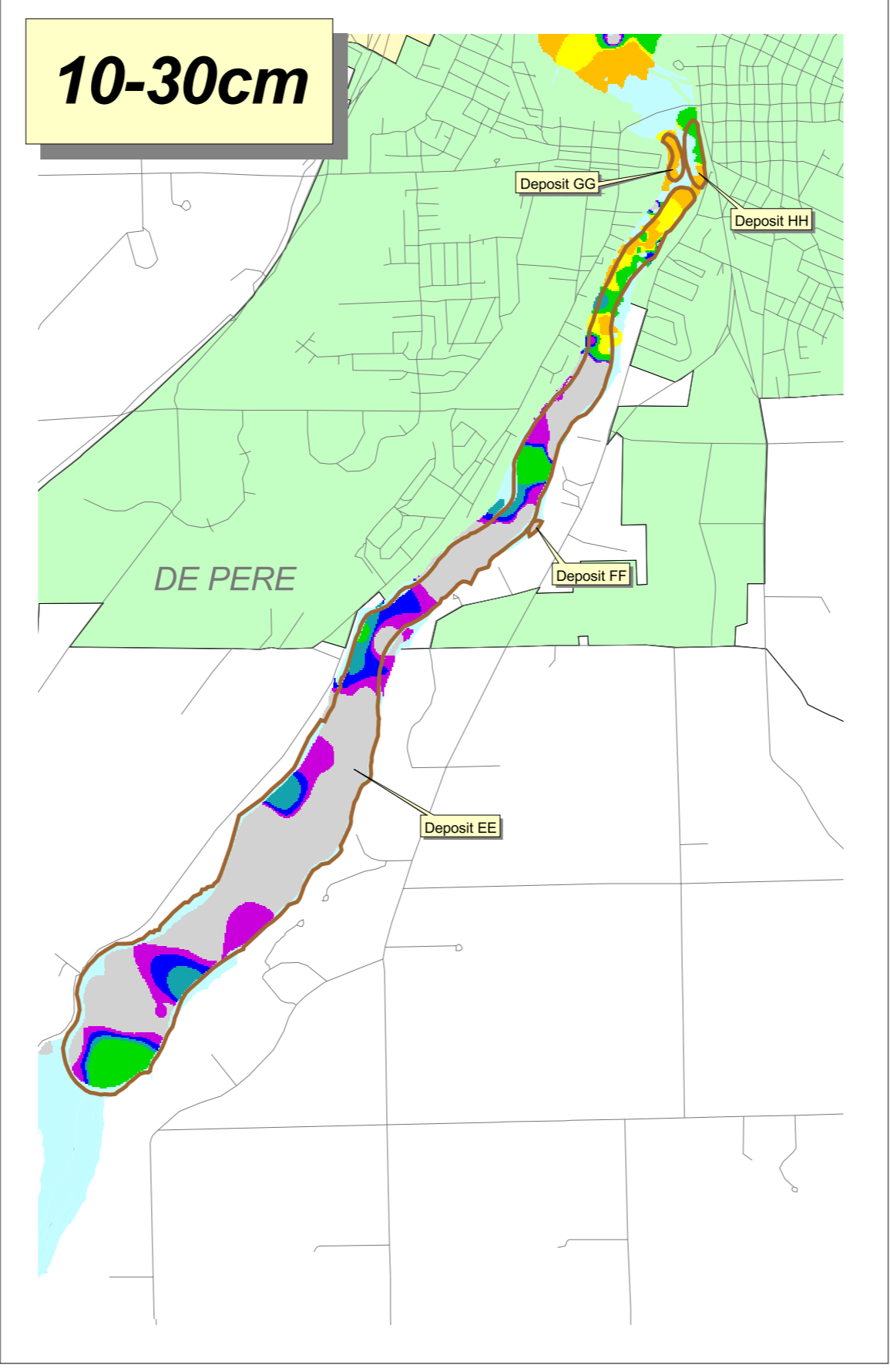
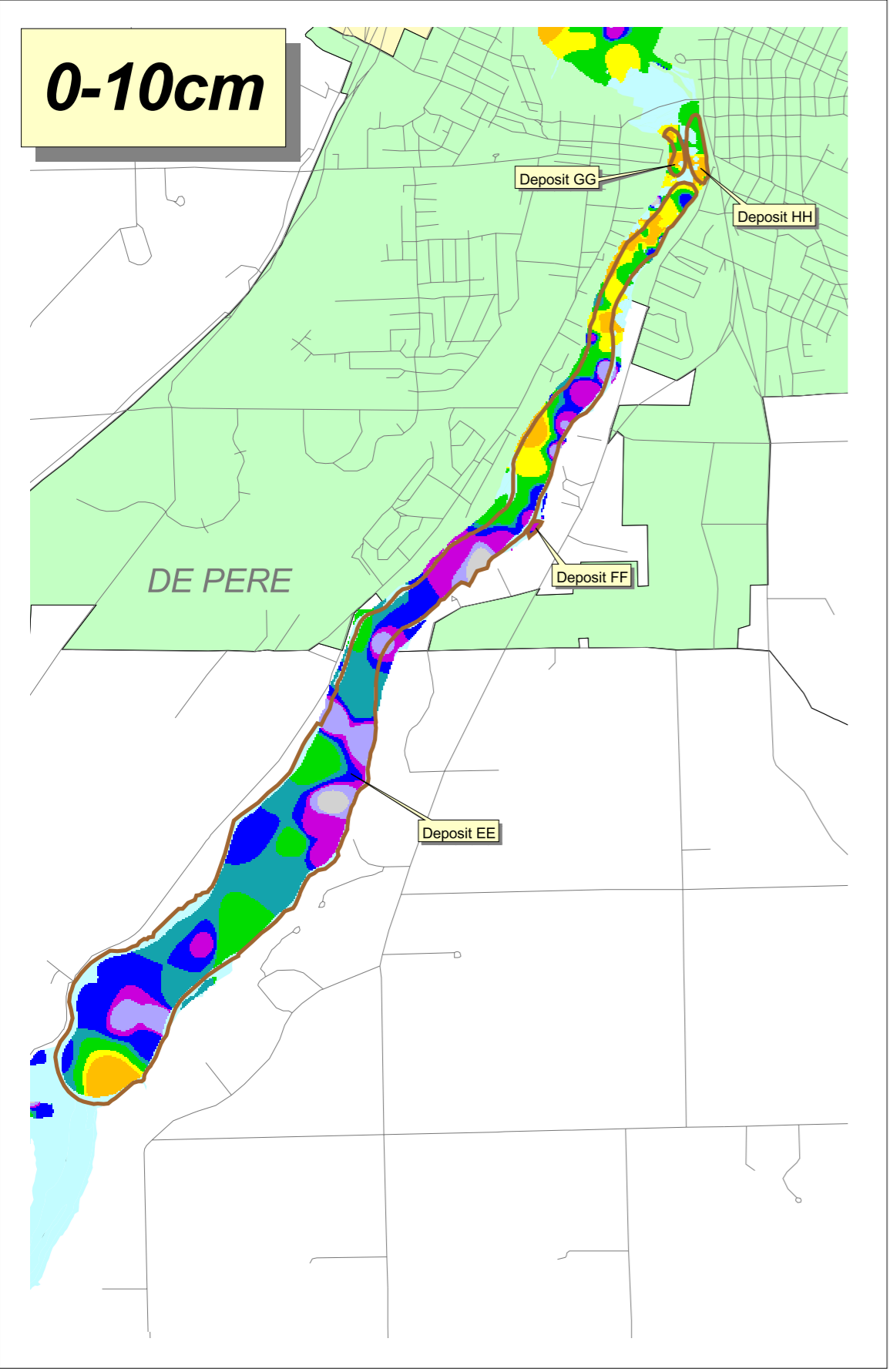
- NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
 2. PCB sediment concentration data obtained from WDNR, and was generated in ArcView Spatial Analyst, version 1.1.
 3. Distribution of PCB-impacted sediment defined by interpolated depth intervals (layers) below surfaces greater than 300 cm depths. Assume no exceedences beyond depths shown.
 4. The less than 50 ug/kg layer implies the presence of soft sediment with detectable PCB concentrations.



NOTES:

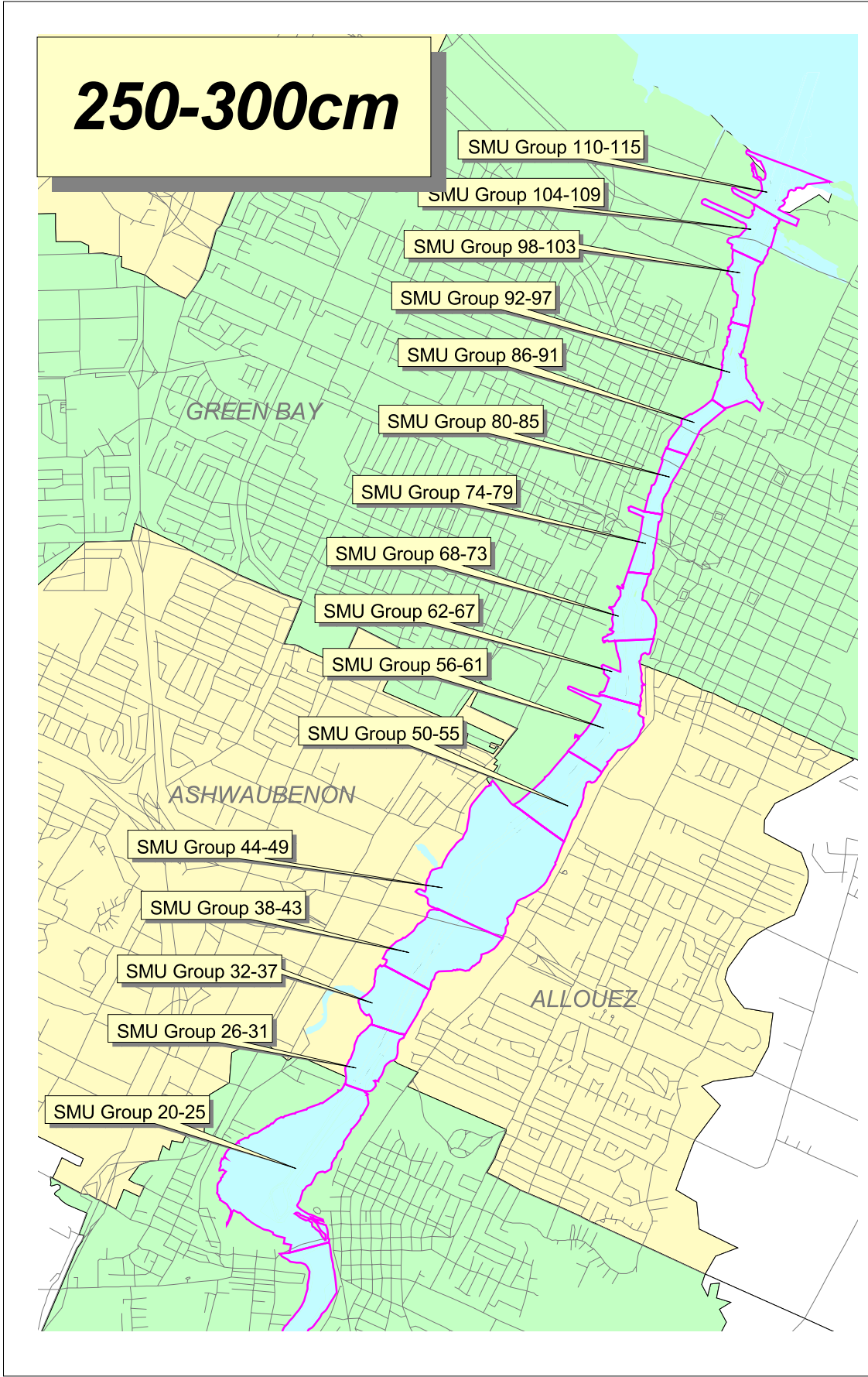
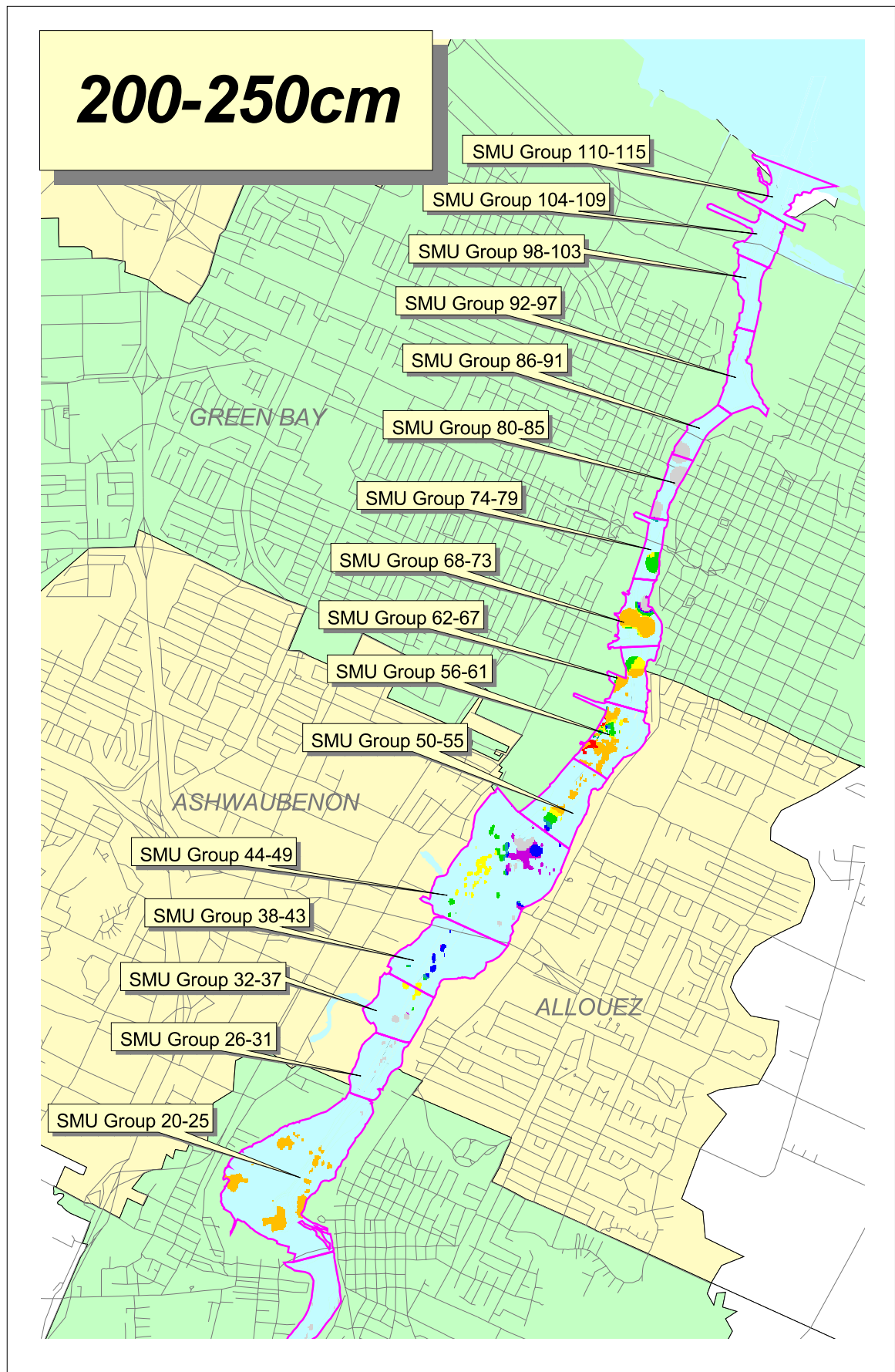
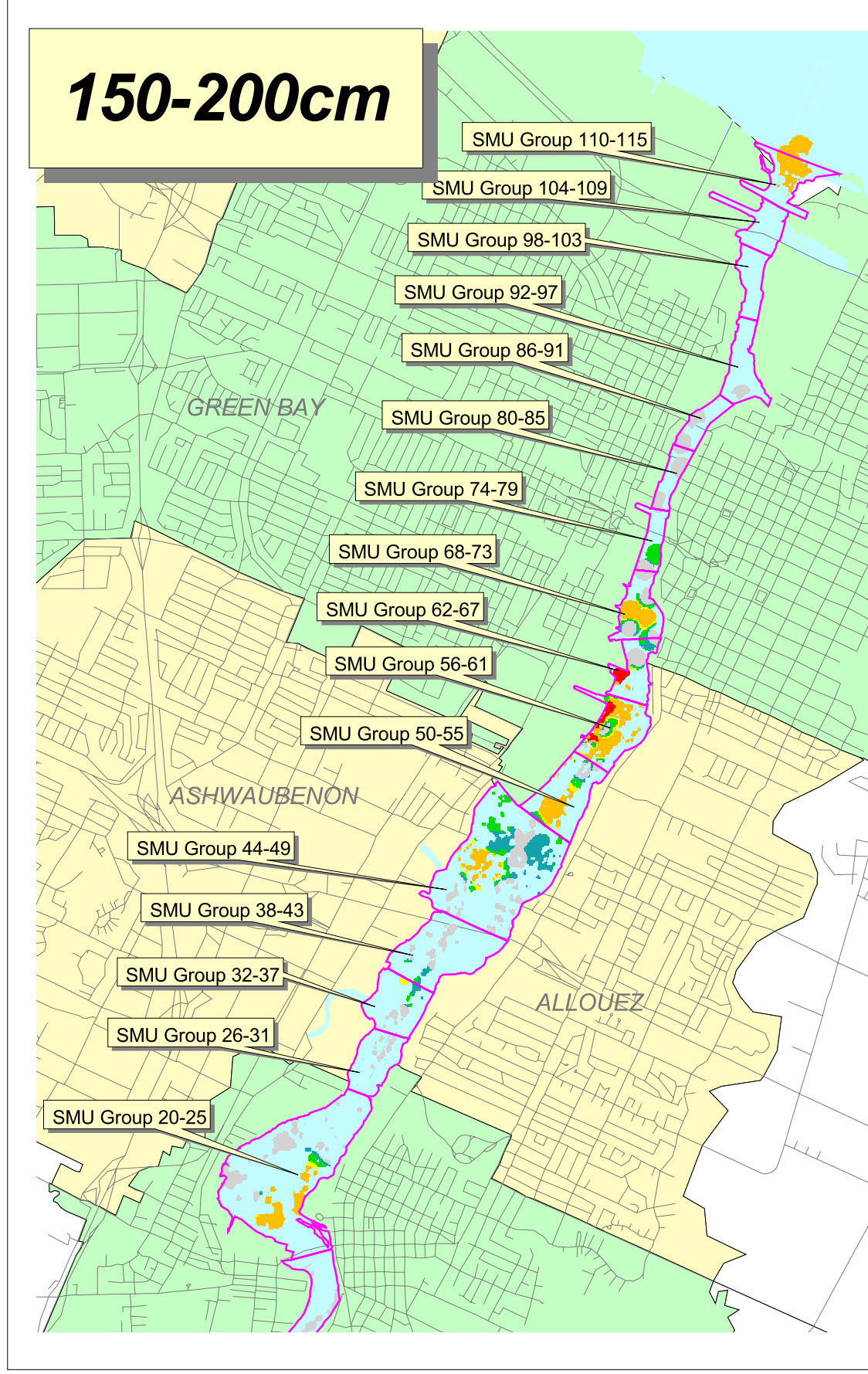
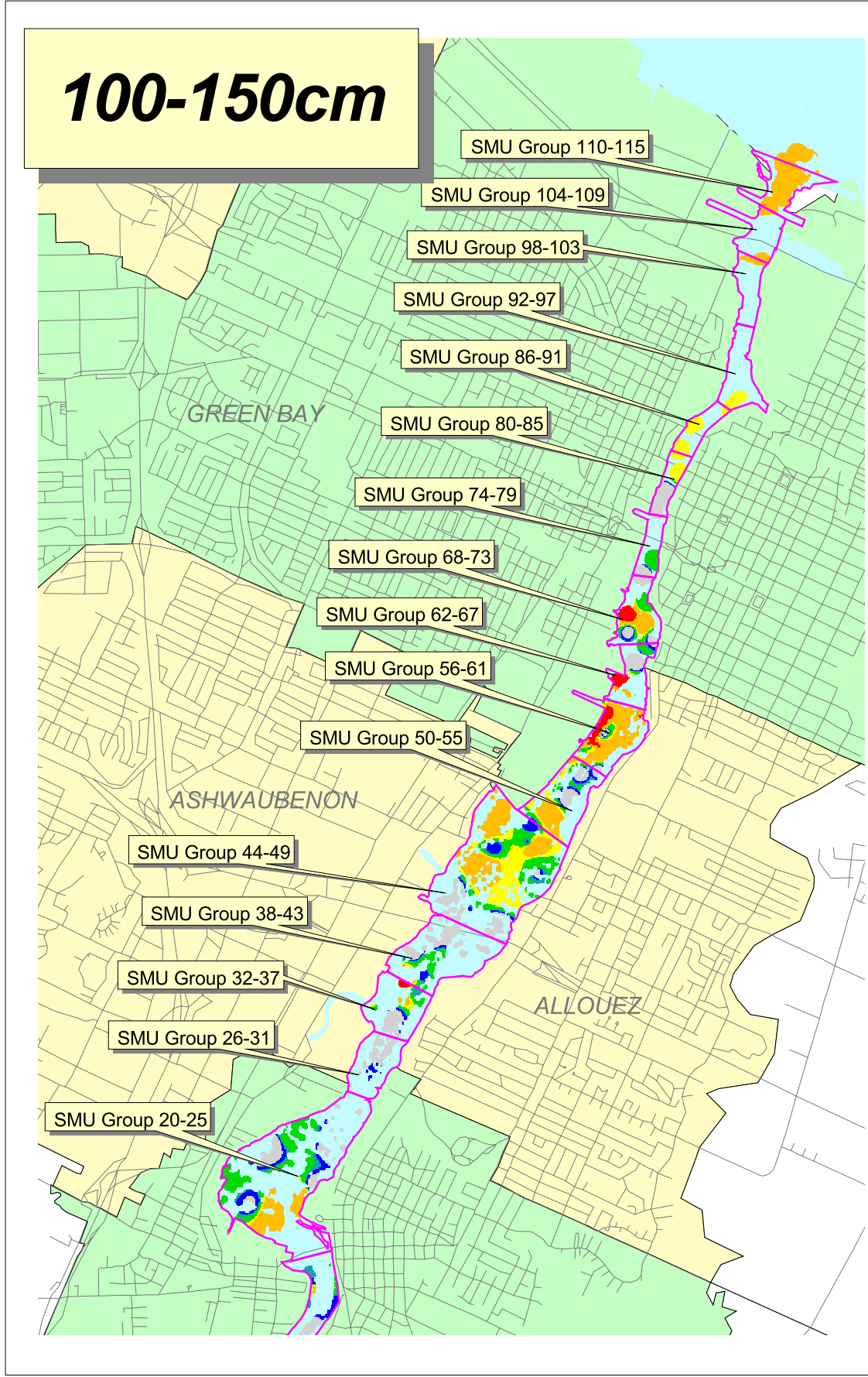
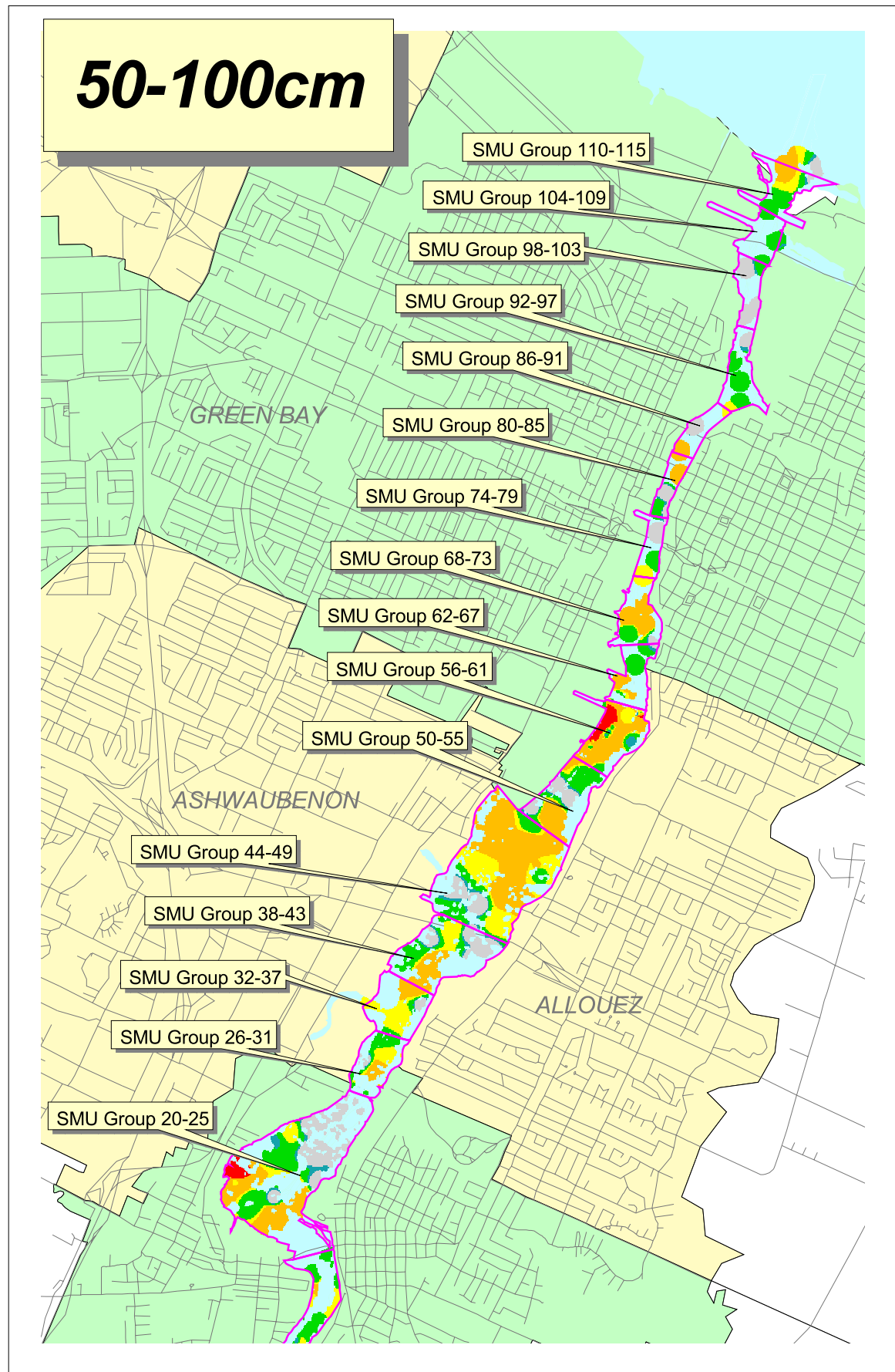
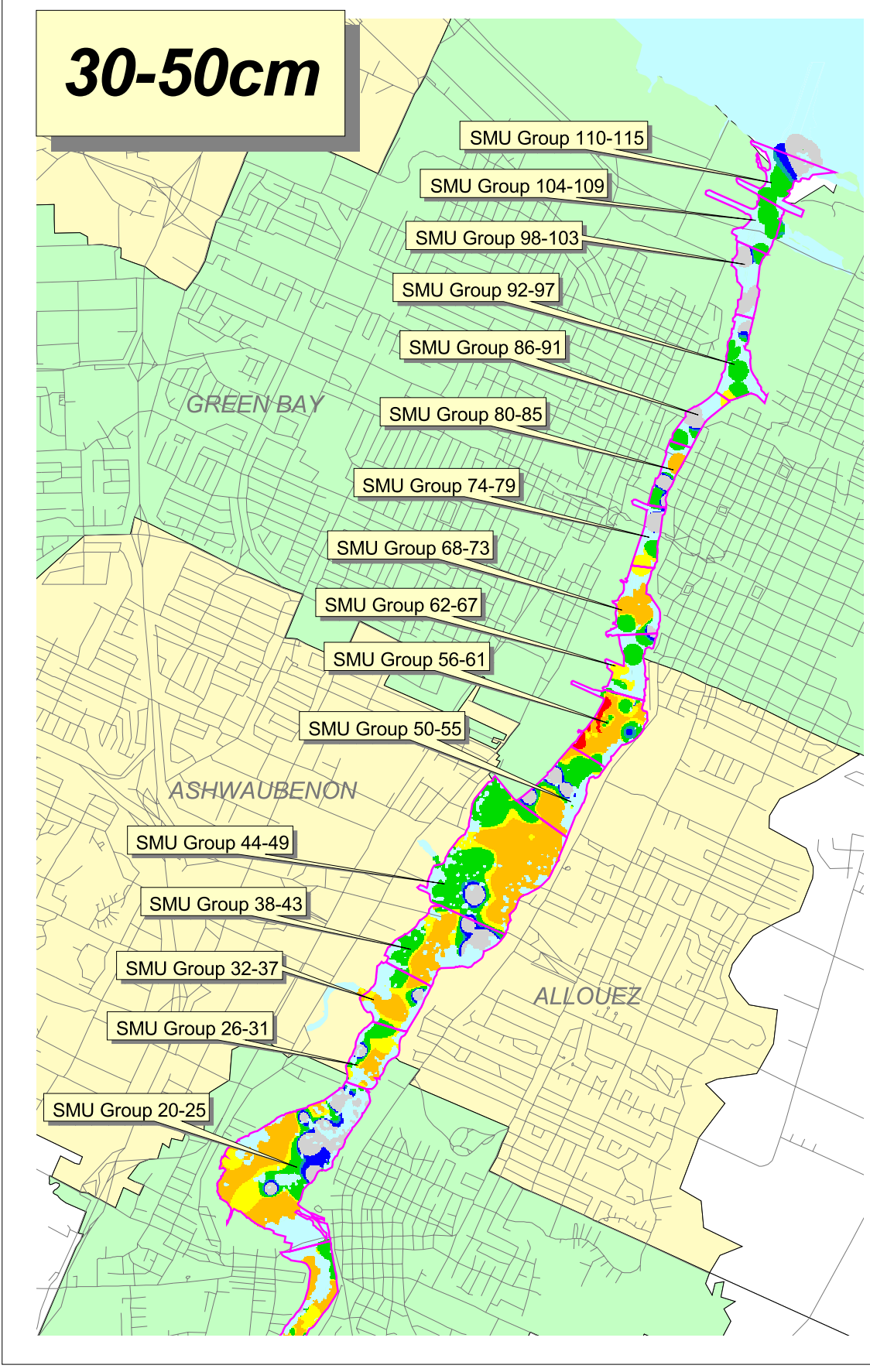
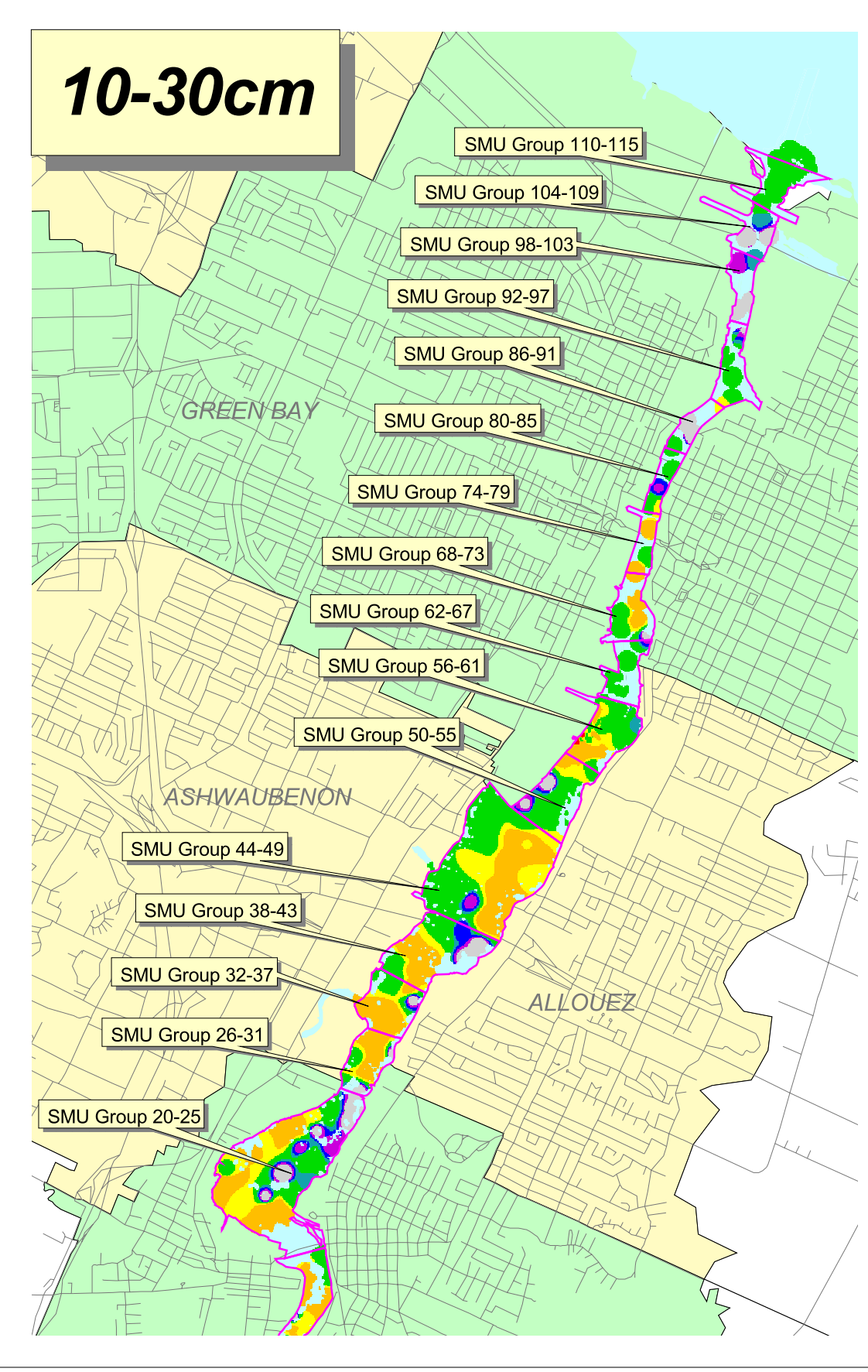
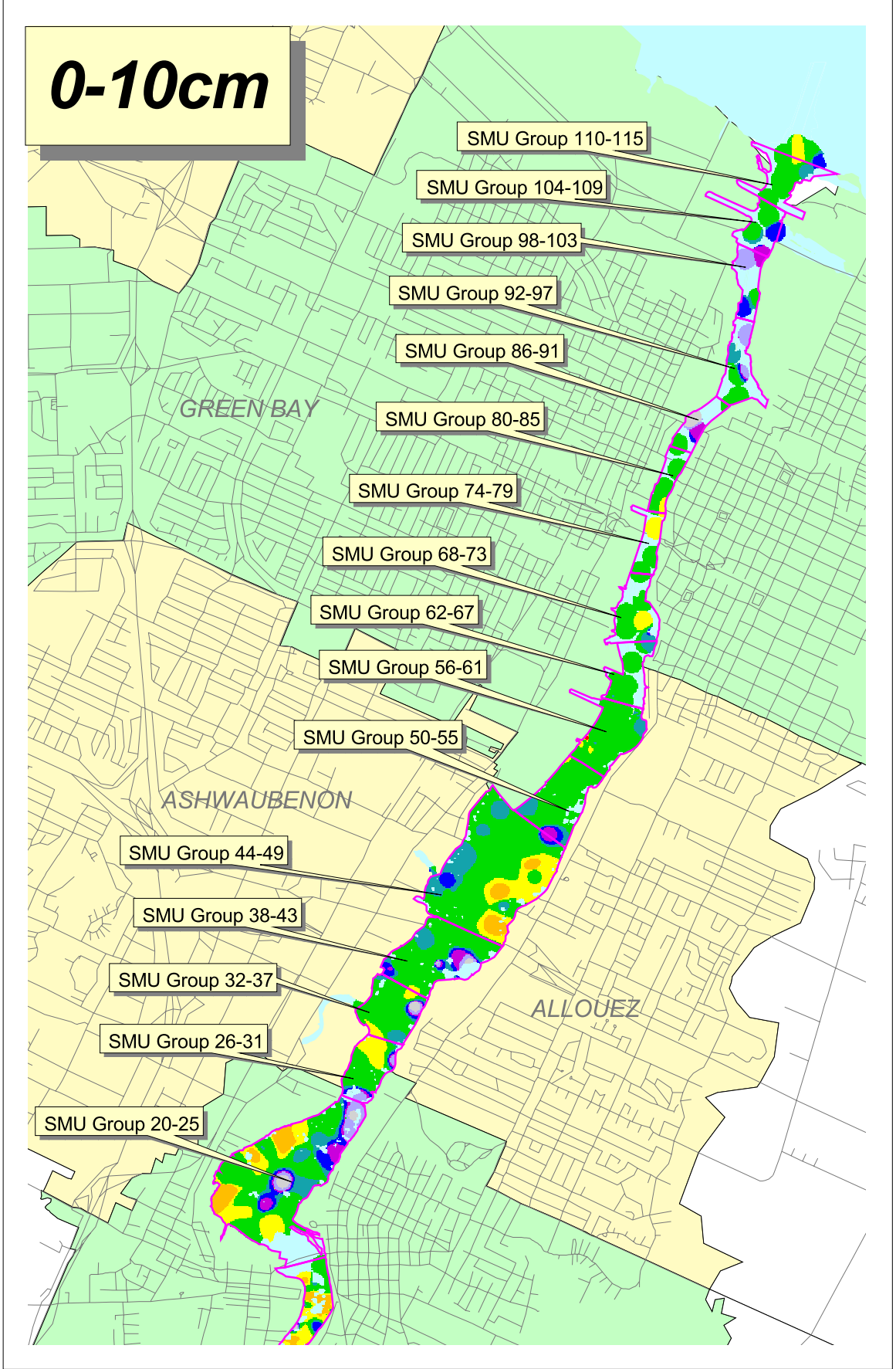
1. Basemap generated in ArcView GIS, version 3.2, 1998, and TIGER census data, 1995.
2. PCB sediment concentration data obtained from WDNR, and was generated in ArcView Spatial Analyst, version 1.1.
3. Distribution of PCB-impacted sediment defined by interpolated depth intervals (layers) below surfaces greater than 300 cm depths. Assume no exceedences beyond depths shown.
4. Deposit N has been removed, but is still shown for reference.
5. The less than 50 ug/kg layer implies the presence of soft sediment with detectable PCB concentrations.





NOTES:

1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. PCB sediment concentration data obtained from WDNR, and was generated in ArcView Spatial Analyst, version 1.1.
3. Distribution of PCB-impacted sediment defined by interpolated depth intervals (layers) below surfaces greater than 300 cm depths. Assume no exceedences beyond depths shown.
4. The less than 50 ug/kg layer implies the presence of soft sediment with detectable PCB concentrations.



PCB Sediment Concentrations (ug/kg)

	<50
	50-125
	125-250
	250-500
	500-1,000
	1,000-5,000
	5,000-10,000
	10,000-50,000
	>50,000

Sediment Management Units

Roads

Water

Civil Divisions

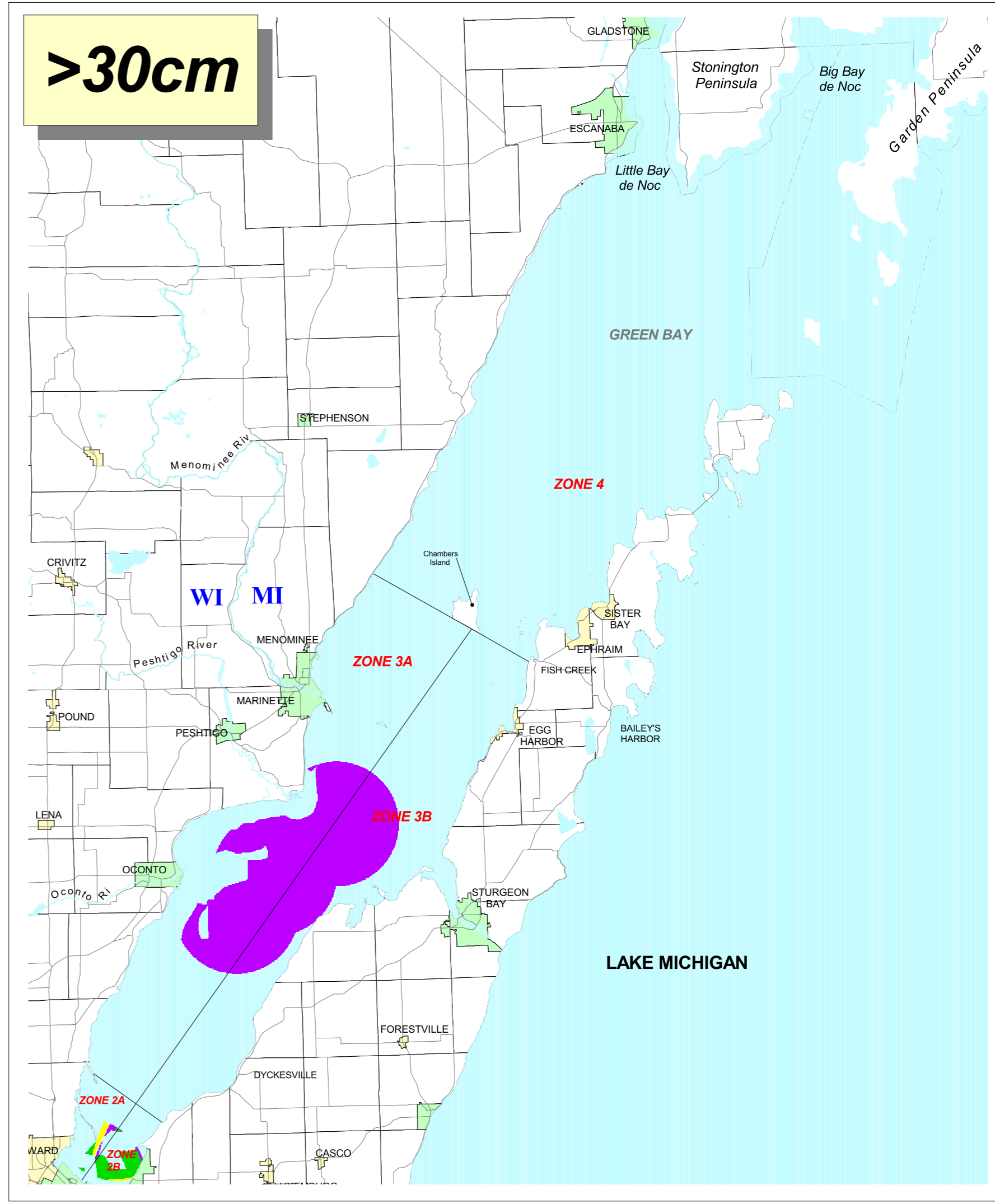
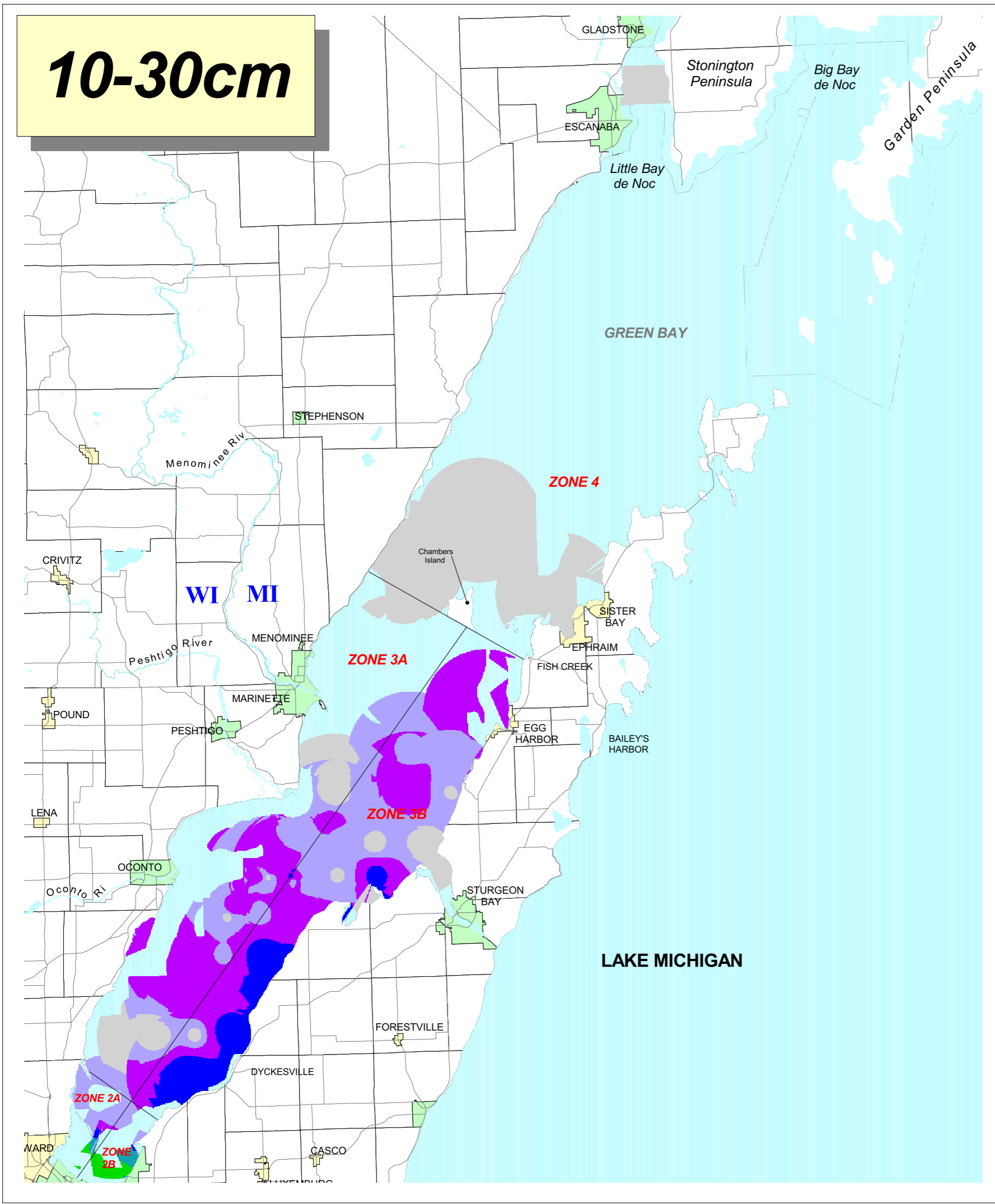
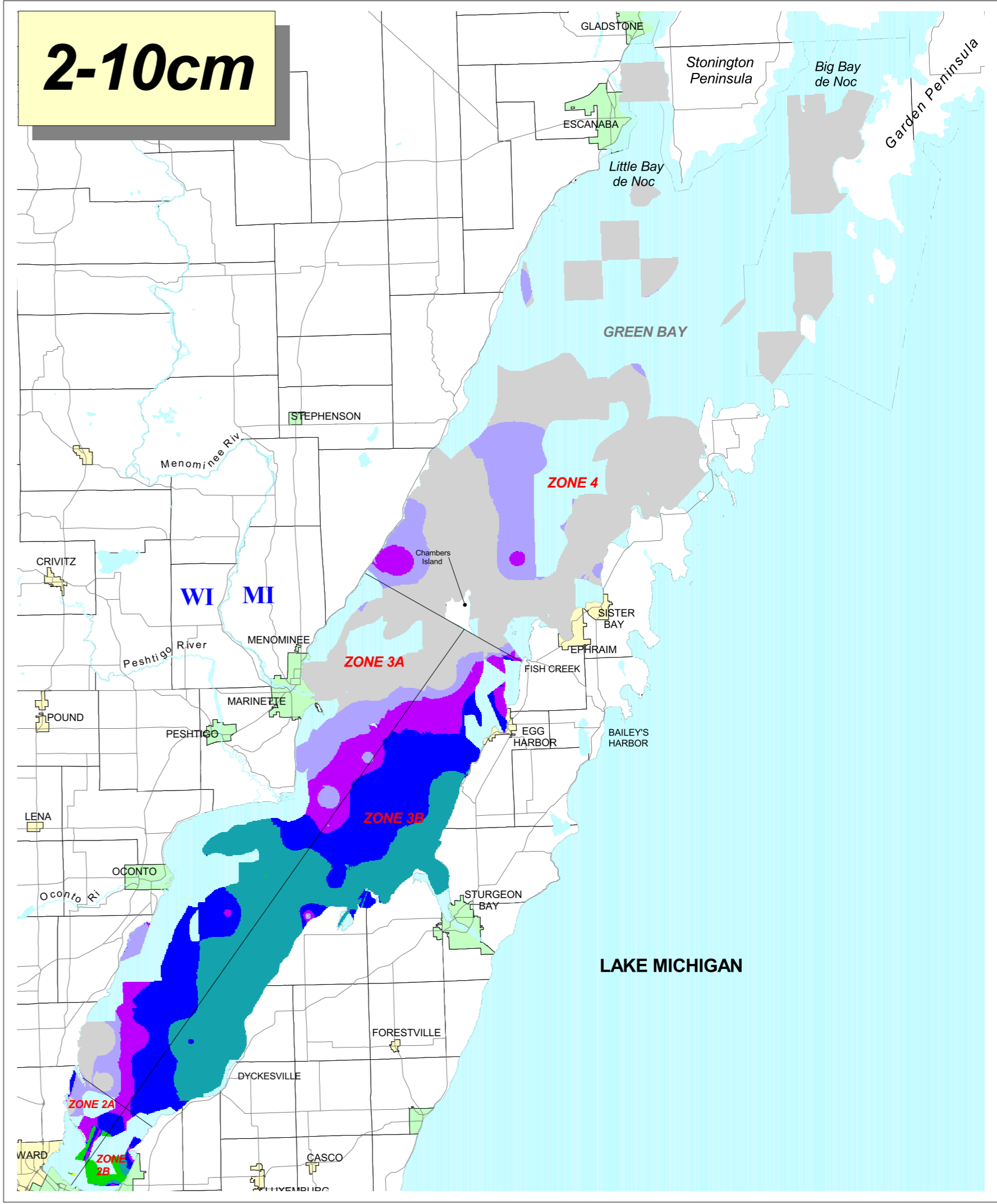
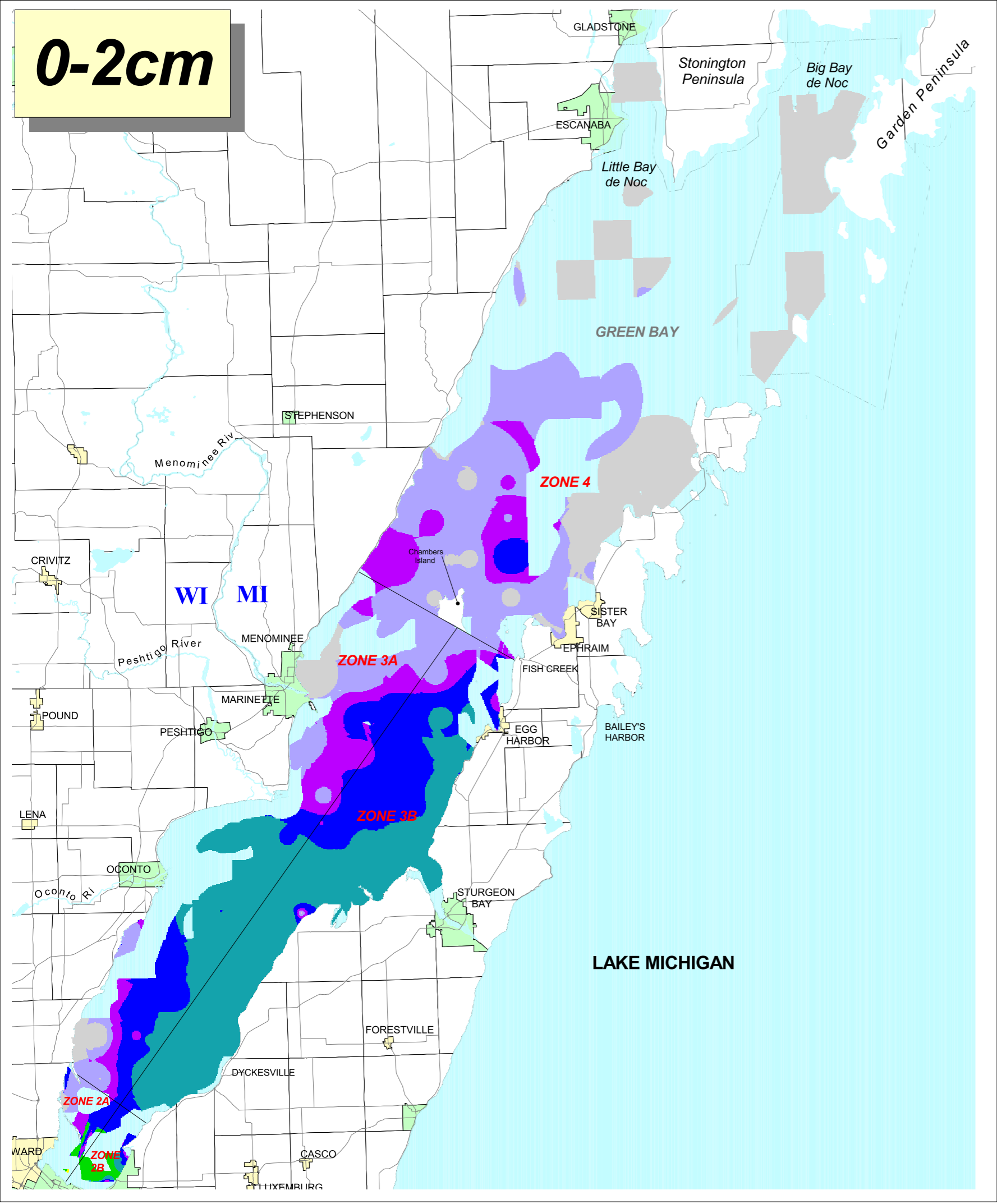
	City
	Township
	Village

2 0 2 4 Kilometers

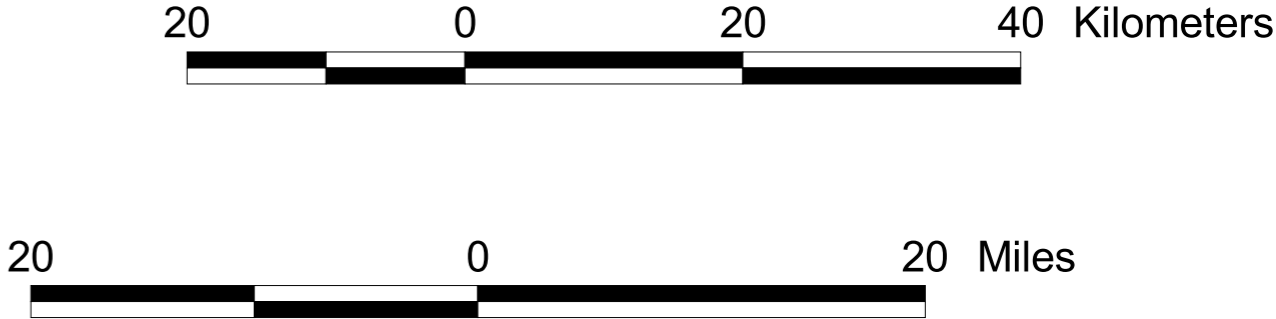
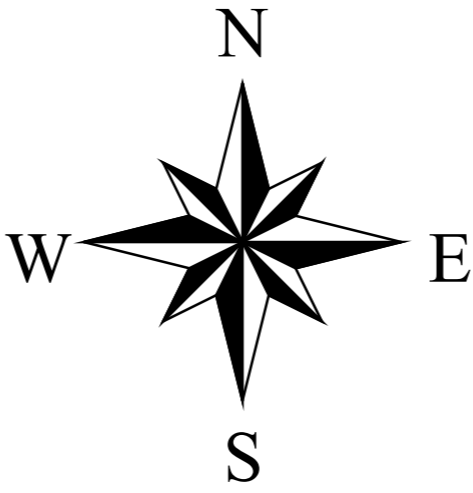
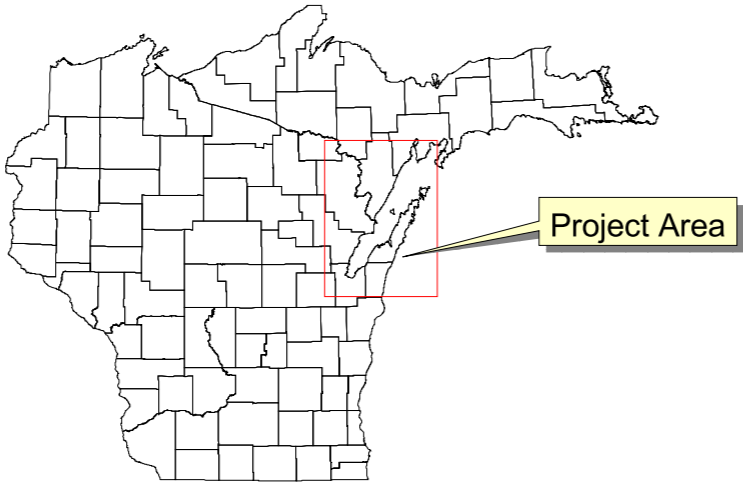
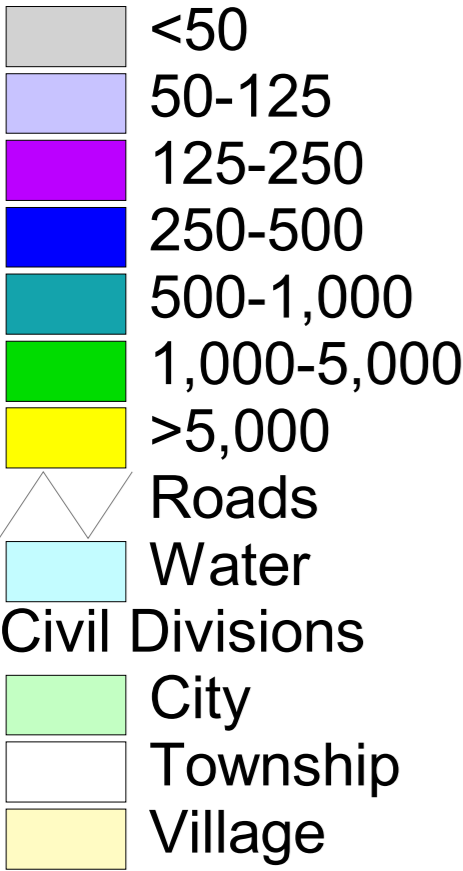
2 0 2 Miles

NOTES:

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2. PCB sediment concentration data obtained from WDNR, and was generated in ArcView Spatial Analyst, version 1.1.
3. Distribution of PCB-impacted sediment defined by interpolated depth intervals (layers) below surfaces greater than 300 cm depths. Assume no exceedences beyond depths shown.
4. The less than 50 ug/kg layer implies the presence of soft sediment with detectable PCB concentrations.



PCB Sediment Concentrations (ug/kg)



NOTES:

1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. PCB sediment concentration data obtained from WDNR, and was generated in ArcView Spatial Analyst, version 1.1.
3. Distribution of PCB-impacted sediment defined by interpolated depth intervals (layers) below surfaces greater than 30 cm depths.
4. The less than 50 ug/kg layer implies the presence of soft sediment with detectable PCB concentrations.



Natural
Resource
Technology

Lower Fox River
& Green Bay
Feasibility Study

Interpolated PCB Distribution in Sediments:
Green Bay

PLATE 2-5

DRAWING NO:
FS-14414-535-2-5
PRINT DATE:
3/8/01
CREATED BY:
SCJ
APPROVED:
AGF